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THE ANIMAL AS A PRIME MOVER.

BY R. H. THURSTON.

[*Concluded from p. 121.*]

PART III. SPECIAL ENERGY-PRODUCTS: ELECTRICITY, LIGHT, ETC.; SUMMARY AND CONCLUSIONS.

Singular and unfamiliar energies are produced by the vital machine, either as incidental to the ultimate purposes of the apparatus, or as special final output for peculiar purposes. For example, it is known that electricity is produced in the muscular and nervous systems, in vertebrate animals, and that in some cases, as in that of the electric eel, in large quantities, and for peculiar and special purposes of offence and defence. The fire-fly, also, produces light for its own special purposes. It is supposed by some authorities that electricity is developed for the use of the internal telegraphic system of all animals and it is a "singular" product only in the sense

that we have not yet been able to make ourselves familiar with it and to determine just how it is employed and in what manner it is generated and transformed. In the case of the light-producer, the product is "singular" in the sense that it is not only unfamiliar as a system of energy production, distribution and transformation, but also as being rarely developed. We know only the glow-worm, the fire-fly and a few other organisms, such as the animalculæ of the tropical seas and certain bacteria, which are capable of transforming energy supplied them into light. In this case, it is also singular that the light produced should be almost, if not entirely, unmixed with heat, and, in this sense it is the most economical light production known. These two examples of singular product are so important and suggestive, as well as interesting from their mystery, that they demand careful consideration, particularly at the hands of the engineer.

Electricity has long been recognized as a vital energy, and the fame of Galvani, the distinguished professor of comparative anatomy at Bologna (1737–1798) was mainly established by his striking discovery (1786) of what is now familiar to biologist and physicist alike, as "animal electricity," or, as Daguin calls it, *l'électricité vitale*, the "vital fluid," according to the discoverer himself. The famous controversy which at once arose between Galvani and Volta, the contemporary professor of physics at Pavia, and which led to the publication of Volta's dictum: "When two heterogeneous substances are in juxtaposition, the one always assumes the positive the other the negative, electrical state," was a first step toward the determination of the fact that as externally produced currents will always affect the nerves and muscles, so internal currents may always be found, capable of affecting external substances. Nobili's discovery of the "proper current" directed from the foot toward the head of the frog (1827), as predicted by Humboldt just thirty years earlier; Matteucci's extended researches of later date, and the still more striking investigations of DuBois Reymond (1842), have proven both the existence of such currents in the animal machine and a drift, also, of electricity outward from

interior of muscle, or nerve, to the surface, which may probably be taken as a "leakage current," due, in part at least, to the fact that, even here, insulation is not perfect. The last-named investigator showed that the more powerful the muscle, in its natural condition, the stronger these electric currents; the heart, for example, exhibiting powerful currents and the muscular system of the intestines a comparatively weak flow. His well-known experiment, in which the galvanometer is made to reveal a current passing from an unflexed arm to the other side and into the arm, which, contracting its muscles strongly, grasps an object forcibly, especially interests the student of the vital machine as indicating, in correspondence with the fundamental laws of energetics in this case of electric action, as in thermodynamic operations, the reduction of the energy-supply by conversion into mechanical work.*

The experiments of the Italian physicists, and of Dr. Ure, on cadavers, are familiar proofs of the substitutive value of the electric fluid and the vital fluid, if, indeed, they are not evidence of their identity, and the still more familiar experiences of all who have had to work with electricity in any form at moderate or high tensions may be accepted as more convincing testimony of the relationship of the one form of energy to the other. The discovery by Pouillet, and the later investigations of Donné, Bequerel, and others relative to the now well-recognized form of vegetable electricity, constitute an interesting, if superfluous, confirmation of the idea that nature employs the electric current in her work much more generally than is popularly supposed.

The identity of animal electricity with the familiar forms of that energy is, perhaps, best shown by the fact that where, as in the gymnotus and torpedo—the best known among some fifty such creatures—the fluid is made the means of attack and defence, thus necessarily being given considerable volume and tension, it responds to every test customarily employed to identify and measure the voltaic current.

* Recherches d'électricité animale. Annales de Chemie et de Physique, 3e serie, t. xxx, p. 119.

The assumption which, perhaps, may now be fairly taken as possessing a basis of probability, that electrical or some related or in many ways similar form of energy may prove to be an intermediary between the chemical energy known to be a necessary initial action in the reduction to the active form of potential energy supplied to the vital system, and those ultimate energy-products—mechanical power, heat, sometimes light, and always physiological manifestations—is strongly corroborated by the facts developed by research in those organisms which most extensively and strikingly exhibit that kinetic energy. It is known, not only that about fifty creatures are capable of applying the electric fluid to their own purposes, in defence and in pursuit of their prey, but that all species of the ray family have at least rudimentary electric organs, a fact first stated explicitly probably by Robin. Five species are known to be capable of producing a sensible, often powerful, electric discharge. Muschenbroeck, Walsh, Davy, Becquerel, Breschet, Linari, Matteucci, Moreau and others, some of whom have been elsewhere mentioned, have shown this fact and have revealed distinctly the identity of this energy of these fishes and other creatures, with the electricity now familiar to us in a thousand daily operations. Marey has shown that the discharge is effected by transmission of the mandate of the will to the storage battery of the animal at substantially the same rate that other nerve-actions are propagated.* He sums up his facts in a form which suits our present purpose well.†

He concludes:

(1) The rapidity of the nervous agent is identical in the torpedo and the frog affected by the electric discharge.

(2) "Lost time" exists and has the same measure in the electrical apparatus of the torpedo and in muscle, and the same is true of its endurance.

(3) The duration of the torpedo's discharge is about the same as the duration of the shock in the case of the electrified frog.

**Journal de l'anatomie et de la physiologie*, 1872.

†Animal Mechanism, p. 57.

(4) This period is about one-seventh of a second.

Davy produced all the phenomena of voltaic electricity from the vital organism; Linari and Matteucci similarly proved its identity, in action and effects, with static electricity and provoked the electric spark from the animal. If the idea of Fritsch is correct that the electrical generating and storage organs of the creature are derived from the skin, it would seem very probable, also, that the source of energy-transformation from potential to the kinetic, or from stored forms to motor forms, may be found in, or under, the cuticle. Bayliss, Bradford and others, however, attribute the currents observed in animals to the flow of fluids, perhaps to simple friction; while Biedermann thinks the katabolic action, breaking down tissue, is the source of the current passing inward; and the anabolic action, constructing tissue, is the cause of the reverse current. If the machine be, in any degree, electro-dynamic, this is a substitution of cause for effect.

Humboldt's account of the employment, by the Indians of Rastro de Abaso, of wild horses in capturing the gymnotus, at the sacrifice of an occasional horse by drowning, after being disabled by the shocks administered by the enraged gymnotus, and his statement, that he himself had received more powerful shocks than he had ever received from the largest Leyden jars, give some idea of the vigor as well as of the character of animal electricity. His experiments with Gay-Lussac, and those of Davy, Bequerel, Breschet and others, show it to be capable of performing every feat and exhibiting every phenomenon familiar to us as the result of voltaic action at high tension.

All research to date proves:

(1) That the electrical current in the animal system is produced for the purpose of effecting energy-transformations of, as yet, undetermined character and extent.

(2) That it is, in the electric fishes, at least, developed at will in quantity demanded for its intended work, as in other displays of energy, up to the limit of the nerve-power of the individual.

(3) That in all its characteristics it is similar to, if not

identical with, voltaic electricity, and thus unquestionably subject to all the laws of energetics, of electro-dynamics, of electrical physics, and of electro-chemical action.

The velocity of transmission of the nerve impulse is from 90 feet per second in cold-blooded, to 100 or 150 feet, in warm-blooded creatures—an exceedingly minute fraction of the speed of the electric current over good conductors. It thus requires about the tenth part of a second to telegraph from the brain to the extremities and obtain a response through the sensory nerves, or to produce reflex motions of muscles. DuBois Reymond found the electromotive force impelling the electric currents flowing in the nerves and muscles of the frog, to have the value of 0·22 to 0·25 volt in the nerve and 0·35 to 0·75 volt in the muscle.* Should it prove the fact that the active energy is electric and magnetic, the low voltage, if confirmed by measurement of the actually operating currents doing their regular and normal work, would indicate great strengths of currents at low tensions. The time required for action, at the nerve center itself, is something like 0·05 second.

Matteucci found that the passage of the electric current from the brain toward the extremities produced contractions of the muscles traversed; while the opposite direction of current caused annoyance, if not actual pain, and seemed only to affect the sensory nerves. He thought that this "polar condition" indicated that such excitation by something analogous to, if not identical with, the electric form of energy, constitutes the "nervous agency" of the system.

What is known to-day simply shows that electricity of low tension and comparatively large quantity, or some related form of energy, is, or may be, a product of transformations occurring in the body, having their source in the potential energy of the food supplied, and is the probable intermediary between the directing power of brain and spine and the elements of the voluntary and involuntary systems of muscles; that this energy is probably in constant circulation in continuously acting organs, and inter-

* Encyclopædia Britannica, Art. Physiology, p. 26.

mittently, at least, in those actuated only by the will; and that the evidence of its presence may always be found in its leakage currents. It is certain that the production of electricity may be increased by the special development of its producing organs to such extent as to become a source of power and of safety to its user and of danger to enemies, exhibiting all the characteristic properties of the familiar forms of moderately high-tension currents.

Anatomists familiar with comparative biology know that the electric cells of the torpedo and its congeners are evolved from the underside of the skin, and by a process which seems simply that of muscle cell production with modification to its special purpose. This fact may be accepted as evidence, worthy of consideration at least, that the muscles contain within themselves the principle of animal power, and possibly, even, that this power is a modification of, if not identical with, the familiar forms of electricity. It is well known that muscular power may reside in the muscle, and that this local potentiality of energy display may be exerted by, and may even act rhythmically in, an organ, as the heart, detached from the body.

Light production by the vital machine illustrates another curious and impressively suggestive method of energy-transformation, the nature of which, and the essential prerequisites for which, are still among the mysteries of this ever-present sphinx.* The light radiated by the living machine has been studied by many investigators, and something has been learned of its production and its characteristics. It is known to be produced in a superficial, transparent tissue, blanketing the parts of the creature exhibiting luminosity, and containing a fat of peculiar structure and composition, which may be burned at extraordinarily low temperatures, giving out a light almost absolutely free from heat. It can thus be utilized in the animal system and, only light being produced, but a minute fraction of the energy demanded in the production of our more familiar

* "The Great Problems of Science," R. H. Thurston; *Forum*, September, 1892.

lights is required for this transformation. In its distribution, but *a fraction of 1 per cent.* of the energy thus expended takes the form of heat; while, in the common gas, or candle, or oil flame, ninety-nine per cent. of the energy is wasted in the form of heat—worse than wasted, since the heat thus produced is usually a source of discomfort as well as a material loss.

The vital machine, as a light producer, thus appears to have an efficiency of production approximating unity.* It has 400 times the light value of the gas flame, 40 times that of the electric incandescent lamp, and 20 times that of the best arc lamp. But the electric current utilized in these cases is derived from heat energy transformed by the heat-engine and the dynamo at, usually, the expense of four-fifths to nine-tenths its original potential amount; thus making the light of nature, as developed in the vital machine, from 200 to 4,000 times as efficient as the best and the worst, respectively, among our present artificial lights, if we assume no wastes in the production of the light-giving material. This would be the case if, for example, its wastes of energy, were there any to occur in the process, were to find use in further transformation, or application, in the economy of the system, as the heat of the exhaust steam of a steam engine in a woollen mill often has as great value for heating purposes as if taken direct from the boiler. Could this kind of light be obtained as the product of artificial methods of energy transformation, the result in economy of energy, of power and of fuel would be among the most tremendous of all the marvellous products of human invention.

Technically stated, the problem is: to produce ether vibrations having a frequency of 5×10^{14} per second, without admixture of other periodicities. Teslá attempts it by electrostatic action; nature does it perfectly by what seem to be chemical processes. How shall we ultimately accomplish this seductive task and emulate nature while comply-

* Langley and Very, on the Heat and Light of the Fire-fly. Smithsonian Contributions, 1892.

ing with those economic laws which always control, and often seriously impede, the progress of the engineer?

Vital force and energy, the force and energy which constitute vitality, which are the characteristics of animal life, may easily be shown to be apart from that higher life of the soul and the intellect which constitutes the *ego*, which *is* the individual. They reside, not in the brain, or in its directing power, the mind, but pervade the animal frame, and are found active throughout the vital machine. Life, in this sense, is seen in the motions of the decapitated trunk of any animal, and the reptiles often live a long time with brain removed. All the functions of purely animal life continue, and the taking of food, its digestion, the act of respiration, that of blood circulation, and the whole "automatic" operation of the system, essential to continued vitality, goes on. This independence of the vitality of all mind is seen in the spermatozoa, which live independent lives for hours, and even in some animals, as in the bats, for months at a time. It is seen, very probably, in the white blood-corpuscles, which, as they float in the stream of vital fluid, change form, seize upon each other or upon the surfaces of their channels, and otherwise exhibit independent life. In fact, it may be fairly presumed that they are, themselves, the principle of life, its method of importation into the animal system. But this is not all. The vital principle attaches to every part, and the heart, removed from the body, continues, for a time, pulsing with its own independent life, the vital principle surviving long enough to produce many repetitions of the natural, rhythmic, automatic movements of the organ. In man—as intellection is entirely unessential to vitality, and, when unconscious, as when sleeping, when under the influence of anæsthetics, when suffering from concussion or other injury to the brain, the whole animal system continues in action with more or less accuracy, under the impulse and direction of the vital power—unconscious life continues, in some cases, weeks and months.

The probability that the vital functions are independent of the intellectual and moral life, and of brain action, is also

evidenced by the facts that the muscle, even when excised, quivers with vitality for a time; that it exudes carbonic acid when working, that it reduces lactic acid, decreases the amount of compounds present soluble in water, and increases the quantity of those soluble in alcohol; decreases glycogen, increases sugar; and all this when the flow of blood, with its burden of nutrients and of oxygen, is cut off from it. Blood entering the living and working tissues is always changed, in life, and issues with a new composition. The tissues are thus "laboratories, in which materials abstracted from the blood are transformed."

An excised intestine continues its peristaltic movements for an appreciable time. The heart of the rabbit beats sometimes a half hour after excision; the right auricle continues after the organ as a whole has become quiescent, and has been known to exhibit motion fifteen hours after death. The same independent and automatic action has been detected in the dog's heart four days after the death of the animal. The cold-blooded animals exhibit still more persistence of this local and independent life of the organ, and the heart of the frog has been known to pulsate with the motions of life, as a whole, for two or three days after removal from its nerve connections. Every organ is a motor; every protoplasmic cell is an elementary vital system.

The motor and other movements of the machine are absolutely independent of the peculiar nervous and mental characteristics of animal life. This is shown not only by the facts elsewhere mentioned in a similar connection, but also by the seemingly intelligent action of the sensitive plants and many other vegetable organisms, by the movement of the vegetable as well as of the animal protoplasms, by the energetic action of the white corpuscles of the blood and of the amœboid cells of both animal and vegetable protoplasms. Heat, light, electricity, chemical and mechanical stimuli, alike, all provoke displays of motor forces and energies in the simplest known forms of vegetable and animal structure, and absolutely independently of intelligence, will, nervous power, special circulatory and respiratory organs or, of

location in the organism of which they form the most elementary part. The rhythmic action of the human heart, the voluntary movement of the animal frame, the entrapping of its victims by the sensitive plant, the motions of the bacteria, the changes of the amœba and the protoplasmic cell, are, all alike, exemplifications of the inherent residence of motor-energy under conditions which involve entire absence of all the machinery of thermodynamic, or electrodynamic, motors of any sort as yet familiar to science.

It is thus evident that the vital energy is independent, on the one hand, of the familiar physical energies and forces, and, on the other, of the mental powers, of intellectual and soul life. It pervades the whole system, as do the physical energies, and may attain great development without reference to the condition of the physical or the psychical energies. The doctrine of Quesne, "psychism," is to this degree afforded some support. But the now universally accepted doctrine of the evolution of the world from an earlier chaos compels us, it would seem, to admit that all energies and forces, and all matter, aggregate out of space, and Quesne's proposition may be extended to every department of physics and psychics. All space is pervaded by heat, light, electricity and magnetism; why not with vital and spiritual energies?

The office of the vital force and its energy is apparently to give direction to the coarser physical energy of the muscle. It is the director of the telegraphic current which notifies the energy of the muscle when and how to exert itself. It co-ordinates the automatic movements, controls the system as a whole, as well as in detail, and is itself the principle of purely animal life. The organ which mainly controls and directs it, which is constructed to differentiate it from other energies, to give it form and purpose, to afford it a vehicle, is the spinal nerve of the vertebrate, and the equivalent organ in other creatures.

The psychical energies, including consciousness, intellection, emotion, which are essential characteristics of the vital machine, and which, in the case of those with which we are principally concerned, at least influence to an important

degree its power, endurance and efficiency, all depend, for their effective display and fruitful exertion, upon the preservation in good health and perfect form of the upper brain. A touch upon the surface of that organ impairs the action of the mind; the destruction of a ganglion takes away the power of expression if not of thought; the lesion or degeneration of its tissue measures a proportional loss of psychic energy. With the organ sound and strong, its action depends, as every day's experience shows us, upon its nutrition and repair. Like the body, it is seen to be a machine which guides and applies energies derived from external sources. All its energies come of an initial supply brought, through the blood channels, from the digested food; and both body and brain exhibit characteristic modes of guidance and application of the transferred and transformed energies originally stored in air and food. Body and brain are apparatus for absorption, transformation and employment of characteristic forms of energy. Their methods of absorption, modes of transformation, and processes of application constitute important and attractive, as well as legitimate, problems in physical research. Tracing back the path by which all matter came in from space to construct the material world, and retracing the path over which the energies came out of the ether, and its accompanying stock of all the energies, are companion problems.

The origin of energies displayed in the vital machine is found in the food consumed, and the apparatus of the body is simply, as is now well proven, employed in the freeing of these energies from their potential form in the chemical affinities of oxygen for carbon, hydrogen, nitrogen and the elements of various other compounds, and the diversion and direction of the resultant energies of various kinds and always equivalent quantity, in the performance of internal and external work. Brain, nerve, muscle, gland, all give proper direction to appropriate energies; none originates energy or has power, intrinsically, of doing work. They are all characteristically and kinematically similar to the organs of the machines constructed by man. But the ultimate physical source of all energies, so far as identified, is

the heat and light of the sun; while, in turn, the source of the energy of the sun's rays is presumed to be the mechanical energy of colliding atoms, molecules, star-dust, all celestial bodies, the comets, planets, suns, worlds. The distinctive energies are simply, as we suppose, different modes of motion of atoms and molecules and masses, if physical; but we find no light yet thrown upon the nature of the more subtle energies of vitality, of intellection, of mind, or upon their relation to matter.

Conclusions of serious import, of singular interest, of engrossing attractiveness, and of wonderful possible result, may be deduced from what has preceded; some of these conclusions are positive and certain, some extremely probable, others bare possibilities, so far as we can now trace them, and the possibilities are of such inconceivable magnitude and importance, should they be found to have a substantial basis, that, great as are the consequences of the positive deductions, the further investigation of the potentialities will undoubtedly be considered by men of science a matter of even superior importance. Some of these conclusions are:

(1) The vital machine is not a heat-engine, subject to the thermodynamic laws governing all known forms of thermodynamic machinery produced by man up to the present time.

We cannot assert that it is not a heat-engine in the sense of being a machine, which, by as yet undiscovered methods, directly transforms thermal into dynamical and other forms of energy; but it certainly cannot employ expansible fluids and transform energy by their expansion through a wide range of temperature, and it as certainly does greatly exceed all heat-engines in efficiency, both ideal and actual.

(2) The vital machine is an energy-transforming apparatus, in which the supplied energy is employed in useful transformations in far higher degree than in any energy-transforming machine or system yet produced by man to render available the potential energy of oxidizable substances.

(3) The vital machine must operate through methods of

energy-transformation yet unknown to science, though undoubtedly absolutely scientific and intelligible, once discovered.

The source of energy is perfectly well known, and the primary steps of the process determined, up to the completion of the preparation of the substance containing the potential energy furnished for transfer into the organs of the body, and for immediate transformation by chemical action. The resulting products are all probably identified and most of them well understood and quantitatively determinable; but the intermediate processes of transformation of potential into actual energy, and of transformation of one form of energy into another, as yet are veiled from our sight and concealed from our touch.

(4) These methods, whatever their character, produce mechanical energy more cheaply, as measured in energy consumed, than any known prime motor; develop heat at minimum cost in the same terms; in some cases produce electrical energy in considerable quantity and at high tension, by some probably direct transformation; occasionally produce light of almost absolute purity and perfection of economical character, and, in all intelligent creatures, supply the mind with an instrument utilizing physical energies for intellectual demonstrations.

(5) All these products being considered, this vital machine is enormously more efficient than any apparatus yet invented by the human mind, and illustrates methods of energy-transformation which, if they could be applied in industrial operations in place of the heat-engines, would afford inconceivable amelioration of the condition of the race, and to a less, but nevertheless considerable, degree, of his attendant creatures, both by giving the power of securing the utmost possible duty from our stores of latent available energy, and by prolonging the life of the race by indefinitely removing the period of exhaustion of those stores.

(6) The best evidence yet secured by research seems to indicate that the method of energy-transformation in the vital machine is one which directly transforms the potential energy of the food, as developed by chemical combinations,

into kinetic form, sometimes perhaps simply by chemico-dynamic change, sometimes by chemico-electric transformation; and this in turn, and possibly also the energy due to oxidation of food, and, to some extent, of the muscle itself, into mechanical power, into the vital energy of the automatic system, and into the form of energy producing brain-work.

(7) The vital machine may produce electricity as one principal output of its working processes, and probably by some direct system, without intervention of either heat-energy or dynamical power.

(8) The vital machine may produce light-energy in substantially unadulterated form, and by some process which does not involve either high temperature or the production of heat, or other energies, to be rejected as waste.

(9) It seems most probable, in view of what has been here collated, that the vital machine is some form of chemico- and electro-dynamic engine.

We know that the vital machine is not thermo-dynamic in the sense of being a heat-engine of any known class. We find in electricity the apparently next most available form of energy for use in transformation into dynamic and thermal and other forms, and many accept this as a provisional, a working, hypothesis. This was long ago hinted at by the greatest scientific men, the greatest minds, it would perhaps be fair to say, that have illuminated the history of the race. A century ago, Benjamin Thompson, (Count Rumford) a keen "Yankee," with uncontrollable inclinations toward scientific research, showed, to his own satisfaction, and to the extent of proving to others its probability, that the animal system constitutes a machine of higher efficiency than any steam engine.* Joule, as long ago as 1846, working with Captain Scoresby, concluded that the animal motor "more closely resembles an electro-magnetic engine than a heat-engine," and this is reaffirmed by Tait in our own day.† Sir William Thomson, now Lord Kelvin,

* "Rumford's Essays," 1800.

† "Tait's History of Thermo-dynamics."

in his papers of about 1850, adopts the idea of Joule, and introduces the principle of Carnot, and says explicitly: "When an animal works against a resisting force, there is not a conversion of heat into mechanical effect, but the full thermal equivalent of the chemical forces is never produced; in other words, the animal body does not act as a thermo-dynamic engine, and very probably the chemical forces produce the external mechanical effects through electrical means." We have now seen how all investigations made before and since that date, so far as interpretable, point to the same conclusion:* that the machine is not a heat-engine.

The possibilities of improvement by simulating or paralleling nature are seemingly stupendous. Could the chemical energy of fuel oxidation be directly transformed into dynamic energy; could it even be changed by double or by indirect transformation, as through the intermediary of electricity, and in such manner as to insure a full equivalence of utilizable energy, it is evident that we might anticipate a conversion as economical as we now attain in the transformation of mechanical into electrical energy, and, consequently, many times as large a return for outgo as we at present realize, and correspondingly lengthened time of exhaustion of our stores of primary energy. At first thought, the possibility of an economic gain in power-production, by following nature in energy-transformations through processes which involve the organization of a sugar manufactory as a source of fuel supply, may seem somewhat unpromising; but, when it is considered that sugars and glycogens are but carbon and water, and that the chemist has successfully attacked many other more unpromising cases, as the synthesis of madder, and of the various other commercial substitutes for natural products, the possibilities, even seen from a financial standpoint, are not apparently absolutely to be ignored. Similarly, could chemical energy be directly and fully transformed into light, where needed, and as effectively as nature performs these

* "Mathematical Papers," Vol. I, lviii, p. 505.

operations of energy-transformation in the vital apparatus, the enormous expenditure, the fearful wastes, now going on, even in our production of out-of-door light by the use of the electric arc, would be reduced to a fraction of their present amounts, and to an insignificant fraction of total costs. Could vital energy be identified and brought under control, or could that mysterious energy which is its servant in directing and producing animal power, be securely gained and its processes understood and controlled, it would seem possible that direct transformations of energy—which probably means by influencing molecular and atomic rather than molar motion—might be made possible to man, and all this impressive and wonderful chain of consequences caused to follow.

THE APPLICATION OF ELECTRICITY TO THE BLEACHING OF TEXTILE FIBRES.*

By LOUIS J. MATOS, Chemical Engineer.

The lecturer was introduced by Prof. Sadtler, of the Institute, and spoke as follows:

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

Of all the operations through which the textile fibres are passed in the manufacture of fabrics, none is of greater importance, and it should be remarked with emphasis that none has received a greater share of attention at the hands of practical mill men, technologists and chemists, than that of *bleaching*.

Referring to my subject, I think it most fitting to make a few remarks of an historical character, which may serve as a preface to this most recent stage to which the art of bleaching has advanced.

The art of bleaching has been known and practiced from the earliest times. The products from the looms of the early Egyptians and Phœnicians were brilliant examples of the art, and bore silent testimony to the esteem with which

* A lecture delivered before the Franklin Institute, November 30, 1894.

the fabrics were held by the inhabitants of the other nations who traded with them.

At one time the Dutch appear to have controlled entirely the bleaching of linens, large quantities of which, in the raw state, were shipped from other countries to Holland, to be bleached, and were then returned.

As the trade increased, causing a greater demand for the bleached goods, the time could not be spared for exporting the woven material to be bleached and reshipped, and it became necessary to perform the bleaching at the home of the industry. As a consequence the Irish process was developed, and became a very important trade factor.

The earliest process of bleaching in Great Britain was conducted with great care and attention to details. Fields of immense area were devoted wholly to the practice of the art, which, in the early days of the eighteenth century, was carried on by whole families, and the secrets of the art were handed down for generations from father to son. The trade was an eminently respectable one, and the products of certain bleachers were highly prized.

The earliest method of bleaching, of which we have any positive knowledge, consisted merely in spreading the fabrics on the grass, and exposing them to the action of the direct sunlight and of the dew, for periods of time varying from days to months; and, notwithstanding the many advances made in the art, it is worthy of note that, up to within a very recent date, many of the finest bleached fabrics were treated in this way. It may be remarked that one brand of linens is to-day bleached by a process very closely allied to this primitive one, and which may be briefly outlined as follows: The fabric is treated to an alkaline solution prepared by leaching wood ashes, the action of which is to dissolve from the fibres, such natural, or intentionally added, oils or greases. The material is then well washed in running water in order to remove the last trace of alkalinity, after which the fabric is exposed in the fields for several weeks, The material is then gathered in, worked in a bath of sour milk, again well washed, and the exposure in the fields repeated. According to the kind and quality of the goods,

the entire process here described was repeated several times, or until the desired degree of whiteness was obtained.

As will readily be understood, there is nothing in this process which can, in the slightest degree, injure the fibres, and, as a consequence, many of the treasured linens of the olden time are still in an excellent condition of preservation.

To an eminent French chemist (Berthollet), we are indebted for the first use of chlorine, which reduced the time of exposure in the fields, from weeks and days, to a few hours, but it was long after his experiments that the new order of things became general; in fact, it did not become commercially possible until our common "chloride of lime," or "bleaching powder," became an article of trade. The old school bleachers, of course, fought hard against the new agent, but, like every new and substantial advance in the art, it entered the field to stay.

The advent of bleaching powder marks the commencement of modern bleaching, and I shall take a few moments of your time in reviewing the important methods as applied to the principal textile fibres.

Cotton is never bleached in the unmanufactured condition, but in the manufactured state is frequently subjected to the process. *As yarn*, it is first "boiled out" with very dilute caustic soda, to remove the oil or gum, then washed or not, as desired, then immersed for one or two hours in a clear bath of bleaching powder, then washed to remove excess of bleaching liquor, and finally passed through a very weak bath of sulphuric, or hydrochloric, acid. When in the condition of *warps* (which may be 1,200 yards in length), it is subjected to the same treatment, except that special machines are required for the handling of threads of such great length. In the form of *woven fabrics*, peculiar apparatus, and special care and skill are required, and great ingenuity is displayed in the mechanico-chemical part of the operation. Two systems are in use, which are known respectively as the high pressure and low pressure systems. The essential difference between these lies in the length of

time the goods are subjected to the boiling. In both, also, the operation is divided into two stages. The first, in which the cleaning of the goods is effected, consists in boiling with lime or soda, followed with a weak acid (termed a "sour"), then with soap and soda, followed by a wash. The second is the bleaching proper, in which the goods are brought, for a definite length of time, in contact with the actual bleaching agent, followed by a wash, and a passage through very dilute sulphuric acid, after which the goods are allowed to lie in heaps for a time, then well washed, and dried over revolving cans heated by steam.

Modifications of the above processes have appeared from time to time. A notable one was that of the Messrs. Mather & Thompson, and is admirably suited for warps and piece goods. The important feature in this process resides in the use of carbonic acid gas, by which hypochlorous acid is liberated, which, in turn, effects the whitening of the fabrics.

The previous remarks cover the essential points governing the bleaching of cotton, and I may state that the same principles, with only slight alterations, are applied to the bleaching of linen and jute.

Animal fibres are never bleached with any of the compounds of chlorine, for the important reason that all such compounds impart to wool a yellow color, instead of the white color desired. Wool and allied fibres, however, are beautifully bleached by means of sulphur employed in the form of sulphurous acid gas, the damp yarns or fabrics being suspended in a closed chamber in which stick sulphur or brimstone is burning. The process is too well known to require lengthy explanation. Animal fibres are also well bleached by means of a solution of some sulphite, preferably the sodium sulphite, which yields results equal to the "sulphur house" method.

We have now reached the point where brief reference should be made to the use of peroxides—notably, those of barium, hydrogen, and lastly, of sodium—in the technology of bleaching. Of late, these substances have found extensive application in the textile industry, and their consump-

tion, particularly that of the last two, is continually increasing.

Cotton bleaching with the peroxides has not yet reached commercial importance, but wool and silk are treated in great quantities, the course of the operations with both being substantially the same. Peroxide of hydrogen occurs in the trade as a liquid which reaches the bleacher's hands directly without further treatment than to dilute it largely with water, and to neutralize the bath with ammonia or other alkali, when the fabric or yarn is immersed until the desired degree of whiteness is obtained. Peroxide of sodium, on the other hand, is in the form of a coarse powder, which must first be dissolved in water, then decomposed with a definite quantity of sulphuric acid, the excess of which is neutralized with an alkali, after which the goods to be bleached are immersed. The chemical control of these two bleaches is the same, as hydrogen peroxide is also the agent liberated in the latter case, and suffers the same decomposition. The strength of the baths is determined by means of a solution of potassium permanganate.

BLEACHING WITH ELECTRICITY.

Of all the many and varied uses to which the electric current is put, there is none of more interest to the textile chemist than its application to bleaching. It should be explained at the outset that electricity *per se* is totally devoid of any bleaching properties, and that the textile chemist simply avails himself of the property of the electric current to effect certain chemical decompositions, which he is able to utilize advantageously in his art.

The earliest attempts to use electricity for this purpose are somewhat clouded in obscurity, but it is certain that the credit for the first commercially available results are due to Mr. Eugene Hermite, the inventor of the process I am about to describe in detail.

The bleaching liquor employed in this process is produced by the action of the electric current upon an aqueous solution of a metallic chloride. The one found to be most desirable, owing to its greater economical value, is that of magnesium,

although the chloride of calcium, or of aluminium, may be used with the same result. As will readily be understood, upon passing a current through such a liquid, there occurs a simultaneous decomposition of the chloride present and the water. The result of this electrolytic action is the simultaneous liberation, at the positive pole, of chlorine and oxygen. These two gases—in the nascent state—unite at the positive pole, with the production of an unstable compound possessing, to a very great degree, effective decolorizing properties. Simultaneously also, at the negative pole, the action of the current liberates magnesium, and as the magnesium instantly decomposes an equivalent of

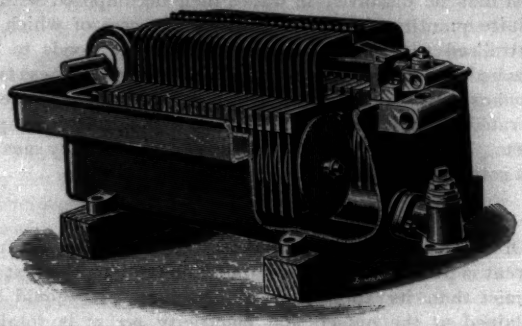

FIG. 1.

water, we obtain, as products of this reaction, hydrogen and oxide of magnesium.

Now, if we add to the electrolyzed solution, or bleach bath, some vegetable fibre—for example, digested and washed wood-pulp—the natural coloring matter of the fibre is destroyed by the highly oxidizing power of the chlorine-oxygen compound previously mentioned, and the chlorine, which is now set free, immediately unites with the hydrogen, forming hydrochloric acid, and this, in turn, in the presence of the magnesium oxide, dissolves that substance, re-forming the original salt in solution. After the pulp has become sufficiently bleached, the liquor is drained off, run back

into the decomposing or electrolyzing vat, and, after the addition of a small quantity of fresh magnesic chloride, it is ready for another operation, on passing the current. The pulp only requires to be washed, as is ordinarily done at the present time in the common bleaching powder process, and is then ready for conversion into paper.

Thus we see that but two elements are consumed in the operation—electricity, and the coloring matter of the substance to be bleached.

The electrolyzer, which is the most important piece of apparatus in the plant, is shown in *Fig. 1*. It consists of a vat, or tank, of galvanized iron, provided with a tube of zinc, perforated with holes in order to facilitate the circulation

FIG. 2.

of the liquors. The negative electrodes are made of zinc in the shape of disks, and are secured to horizontal shafts, which, by proper gearing, are caused slowly to revolve. Between each pair of these disks are placed the positive electrodes, *Fig. 2*, each of which consists of an ebonite frame, holding, with the necessary firmness, a net, or perforated strip, of platinum. Each of these pieces of platinum is soldered by its upper edge to a piece of lead, and is completely isolated. Every frame of the positive poles communicates, by means of a piece of lead, to a bar of copper which traverses the electrolyzer.

The bar of copper to which the positive electrodes are attached, is in communication with the positive pole of the

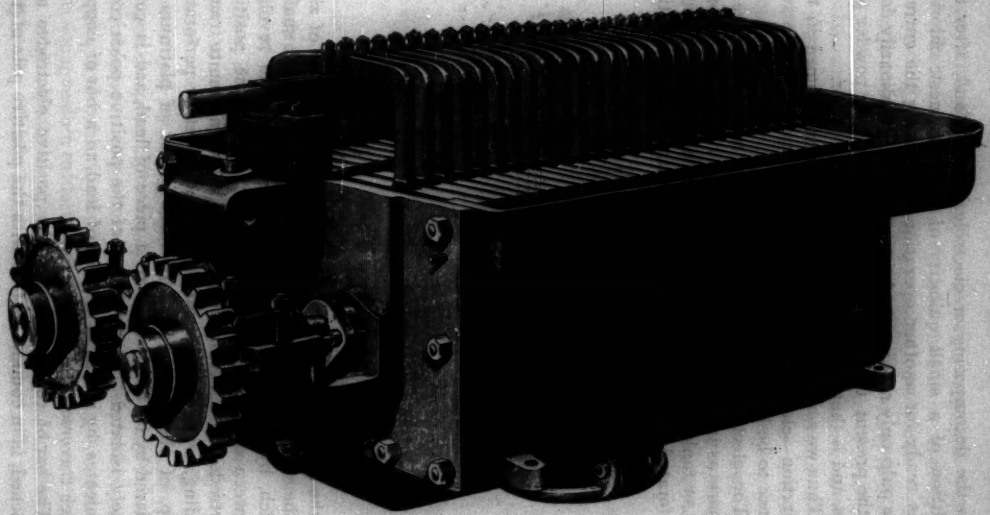

FIG. 3.

dynamo. The current is distributed through all the electrodes of platinum, and passes through the liquid to the disks of zinc forming the negative electrodes, which are connected by means of the tank, or vat, with the negative pole of the dynamo.

In order to maintain the negative electrodes at the proper distance apart, ebonite blades are fastened to the positive electrodes. At the lower portion of the box, or tank, is a gate, or door, which permits of access to the apparatus for cleaning; a valve is also provided for drawing off the liquor should this become necessary.

When several electrolyzers are employed in a battery, the negative pole of one is connected to the positive pole of the next in the series, and so on to the last one.

The current strength ordinarily employed in the electrolyzer is from 1 to 1·2 ampères, and with a corresponding electro-motive force of 5 volts. Instruments for measuring the strength of the current are placed in the circuit, and give at any moment a record of the force utilized.

The electrolyzers require no special attention; about once in every month the apparatus is thoroughly cleansed with water through the door previously mentioned, applied by means of a rubber hose; it is not necessary to dismantle it for the purpose. The wear of the electrodes, in consequence, is very slight.

The conductors, which join the electrolyzers and which bring the current from the dynamo, are made of bars of commercially-pure copper; the cross-sectional area of these bars varies with the distance between the dynamo and the electrolyzer.

It is always advisable to locate the dynamo and the electrolyzer as close to each other as possible.

Fig. 3 shows the large type of electrolyzer, with gearing in place to revolve the negative poles. *Fig. 4* shows a complete electrolyzing apparatus, embracing dynamo, electrolyzer and storage tanks, in position.

The Dynamo.—For this work a very strong type of machine is required, and it should be so constructed as to be capable of yielding its maximum duty—running day and night.

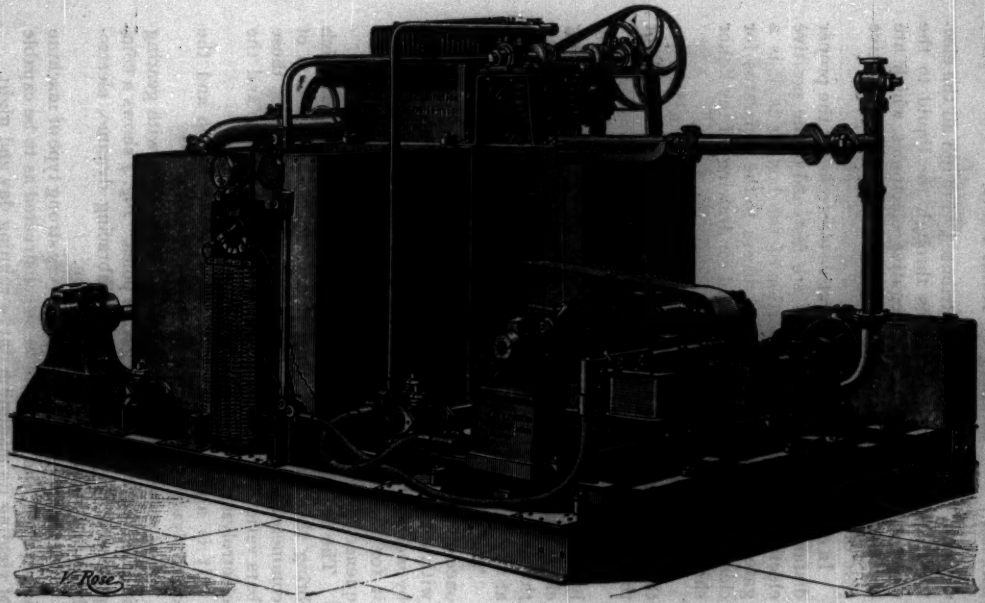

FIG. 4.

The Bleaching.—Bearing in mind the remark, previously made, respecting the peculiar action of chlorine upon animal fibres, it will be understood that the electrolytic process is inapplicable to them. We will confine our remarks, in consequence, to the bleaching of vegetable fibres, in connection with which much has already been accomplished with the process, and where there is still room for important improvements.

The fibre of most importance is, of course, cotton, and of this I shall speak first.

Cotton occurs in the form of a silky hair, which, when examined under the microscope, is revealed to us as a flattened tube, more or less twisted, and of a pearly-white color. It consists almost wholly of cellulose, with certain admixtures which are natural to it, such as moisture, several coloring matters—collectively termed "endochrome" oils—and a certain amount of inorganic salts. The quantities of these admixed substances peculiar to cotton are small, but, in the processes of converting the crude fibre into a manufactured product, certain other substances are added, such as oils, fats, starches, sizes, mineral matters, etc., all of which must be removed before the goods can be properly bleached. To do this it is necessary to subject the goods to a preliminary boiling or scouring.

Electrolytic Bleaching of Slubbing.—In this state, cotton is difficult to bleach, owing to the mechanical obstacles; nevertheless, it is done, and with remarkable success. Preliminary scouring is out of the question, and the electrolyzed solution is allowed to act directly on the material. The contained waxy matters, and those which are insoluble, are not acted upon by the solution, but the latter causes a decomposition of the coloring matter, which is converted into carbonic acid. The pectic acid is changed into a soluble pectate of magnesia, and the remaining mineral matters are dissolved. The greatest difficulty encountered is in causing the liquid to penetrate evenly into every part of the slubbing, but this is overcome by the use of pressure.

The length of time required for the immersion varies according to the color of the cotton treated, according to

the degree of white desired, and also according to the amount of chlorine and oxygen contained in the solution. Compared with the old method of immersion in the chloride of lime solution, the time can be very greatly prolonged without injury to the fibres. After bleaching, the cotton is removed, carefully washed with water slightly acidulated with sulphuric acid; this is followed with a rinse, the excess of water is removed, and the stuff is finally dried in the ordinary way.

Electrolytic Bleaching of Cotton on Cops and Bobbins.—Some difficulty is experienced in successfully bleaching yarn that is wound upon tubes or spools, owing to the resistance offered by the threads when superposed, but, by employing the conditions advised for the bleaching of slubbing, the difficulty is overcome. The cotton is acted upon by the bleach liquor of suitable strength, and, owing to the rapid action of the solution, the fibres are bleached during the ingress of the liquid.

Electrolytic Bleaching of Yarn and Cloth.—These offer the fewest obstacles. Yarn is bleached in a series of tanks supplied with the solution of constant strength from the electrolyzer. Cloth is similarly treated, except that it can be passed through the bath in a continuous form.

Electrolytic Bleaching of Linen and Hemp.—These fibres differ very much from cotton in the amount and nature of the extraneous matters which they contain. Linen is made from the fibrous part of the flax plant. The flax fibres are bound together by a cement-like substance, which must be removed in order to isolate the individual fibres. The removal of this substance constitutes the very important process of "retting," of which several methods are carried on. The oldest, and perhaps the best known, is the retting by fermentation, which is a kind of rotting of the ligneous matter. After this is removed, the subsequent operations of bleaching and dyeing are in order. It has been found that if these fibres are subjected to the action of the electric current in the bleach-tank, the oxygen, which is given up very readily, oxidizes the constituents of the vegetable cement, converting them into resinous

bodies, and thereupon at once proceeds to exercise its bleaching powers. When the fibres have assumed a yellowish or reddish color, the oxidation is finished, further treatment in the electrolytic bath is stopped, the material is removed and subjected to the action of boiling caustic or carbonated alkalies, either with or without pressure. This boiling operation effects the more or less complete removal of these resinous bodies, and leaves the fibres in a very clean and free condition, ready for further treatment. To bleach, all that is now necessary is to subject the fibres to a simple passage through the electrolytic solution, when a white of extreme brilliancy is obtained, and a silky feel is imparted to the fibres, which can be obtained by no other process, if the fibres have been retted in the ordinary manner.

Electrolytic Bleaching of Linen Threads.—Threads made of electrically retted fibres are of great purity, containing, besides cellulose, the natural coloring matter, and the residues of the vegetable cement, and, from what has preceded, it is easily seen that the bleaching of yarns is devoid of any difficulty. In comparison with the ordinary bleaching-powder process, that of Hermite has the decided advantage that the liberated gases, which do the bleaching, do not, as is the case in the old method, act injuriously upon the fibres. A modification of cellulose—termed "oxy-cellulose"—is formed in the old process, which is responsible for a considerable loss of fibre.

Electrolytic Bleaching of Jute.—This fibrous substance is one of a group closely allied to linen, but it has been quite impossible to bleach it on account of its feeble resistance to oxidizing agents. By way of comparison, I will describe the method most generally in use, at the present time, for bleaching this substance:

The goods are scoured in a bath containing half of one per cent. of silicate of soda, and kept at a fair heat; then washed and passed through a bath of sodium hypochlorite, containing about one per cent. of available chlorine; well washed, passed through a weak bath of hydrochloric acid; then washed again. The bleaching by the Hermite process,

which resembles that for linen, consists in the preliminary removal of the cutose and vasculose (vegetable cement) by conversion into resinous bodies, and the extraction of these by treatment with soda or other alkali. The actual bleaching is done by means of the electrolyzed solution, worked in a tank, in the same manner as with the ordinary chloride of lime process.

APPLICATION OF ELECTRICITY TO THE BLEACHING OF PAPER-PULP.

Having considered the several bleaching processes as applied to the textile fibres which are met with in the ordinary course of manufacturing operations, I will now bring to your attention another condition of fibrous materials, the isolation, bleaching and finishing of which, demands the highest qualities of both chemical and mechanical skill. I refer to the manufacture of paper.

The art of paper-making is very old, very interesting, and, when all the points are considered, it is seen to be a very elaborate process. It must not be thought for one moment that the elegant specimens of papers and cardboards, which almost daily come under our attention, are the results of any one series of experiments. As a matter of fact, such examples of skill are the final products of a process of evolution.

Many of you, no doubt, have been through a paper mill, and have seen the process of making great, long sheets, or rolls of paper, of exquisite whiteness and brilliancy, and have seen also the great bins of rags, collected here and there, from which the fine paper is made. For the information of those who have not seen the process, I will describe it somewhat briefly.

The rags are first assorted according to quality, the cleanest and finest pieces being set aside for the very finest linen papers. They are then cut into small pieces and boiled in a solution of lime, caustic soda, or a mixture of lime and soda-ash. This operation loosens the dirt, and prepares the material—called pulp—for the subsequent pro-

cesses. The next operation is the washing, which has for its object the removal of the soda or other alkali used. Then comes the bleaching, which is ordinarily done by a solution of chloride of lime, the strength employed being usually about half a pound of bleach to the gallon of water. The bleaching is done in vats, called "potchers." When the pulp has been sufficiently bleached, it is again washed and run into a machine known as a beater, which serves to reduce to a finer state of division the smaller particles of pulp, after which the material is pumped into the paper-making machine.

Wood, of the poplar, spruce, pine and other allied species, is largely employed in the making of paper, and, strange as it may seem to the uninitiated, products of excellent quality are made from wood, which compare very favorably with the best of those made from linen.

To render the wood fit for paper-making, it must be chopped into small pieces, and boiled with caustic soda in large vessels. This treatment reduces the wood to its elements; that is, it causes the solution of the resinous and other matters which hold the individual fibres together. After this treatment, the pulp is washed with water, and run through a machine, called a pulp-strainer, which removes any particles of woody matter that have escaped disintegration in the boiling. The clear pulp is now ready for bleaching, which is done in almost the same manner, and with the same materials, as with rags. After the bleaching, the pulp is washed and is now ready to be converted into paper.

Referring to the bleaching, paper-makers are confronted with several serious obstacles in the process as it is now carried on with the aid of chloride of lime. The chief of these are its cost, which every one wishes to reduce; the amount of room required; the unpleasantness of the operation; and, finally, the fact that, although fibre has been bleached to a beautiful white, it is lacking in strength. There is another objection, which, though a negative one, is important, namely, the fact that there are some woods, readily available and otherwise desirable for the paper-

maker's use, which cannot be worked because of the impossibility of bleaching them properly by this process.

Chemically, raw wood is closely allied to jute and linen, in having present in its tissues binding materials which hold the fibres together, and which impart a decided color to the wood. Boiling with caustic soda resolves these

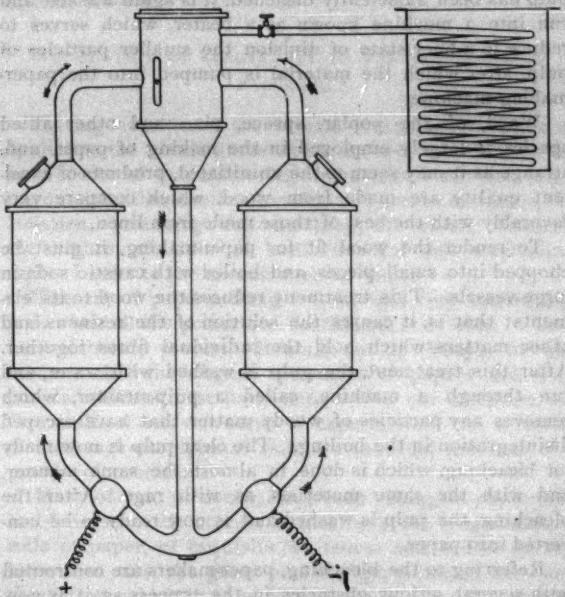

FIG. 5.

binding materials into soluble products which are easily removed by subsequent washing. Now, let us suppose that the boiled and washed wood-pulp is worked, or kept in agitation, in a solution from an electrolyzer. What should happen? Simply this: the remaining traces of the binding material should be completely decomposed, and the coloring matters pervading the wood cells completely oxidized

to carbonic acid, leaving the wood fibres in a condition to truthfully deserve the name "cellulose." This is what the electrolytic processes actually do for the paper-maker, and I shall take a few minutes to describe the methods proposed, and those in use, for making merchantable products.

The process of Karl Kellner, patented in 1885, consists mainly in subjecting the wood-pulp to the action of a solution of common salt at a temperature of 284° F., or thereabout, and with the simultaneous passage of the electric current. The strength of the salt solution is recommended to be about eight per cent., and the time of its action about

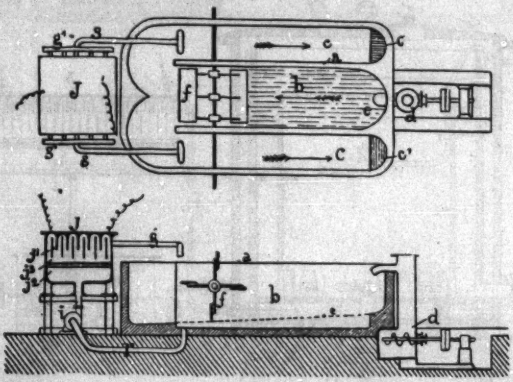

FIG. 6.

three to three and one-half hours. In the Kellner apparatus, the poles, which are of carbon, are placed in the lower part of the apparatus, *Fig. 5*, and connected with the dynamo. In operation, the course of the current is alternated at intervals of fifteen or thirty minutes. For a further bleaching of the pulp, an apparatus is used resembling very much a so-called "hollander," having two compartments suitably connected with pipes, as shown in *Fig. 6*. In this apparatus the bleaching solution contained in the electrolyzer is forced, by a rotary pump, through and around the positive and negative poles and out of the electrolyzer, into the compartments contain-

ing the pulp, which is kept in constant agitation by means of a revolving paddle wheel. The fresh and untreated pulp enters the apparatus at one end and leaves it through a different channel near the same end. The whole machine is provided with a screen which serves to keep the pulp separated from the partially spent, or exhausted, bleaching liquor. This spent liquor is pumped back through the electrolyzer, where it is again rendered active, and the operation is thus made continuous.

Another form of apparatus, embodying in its construc-

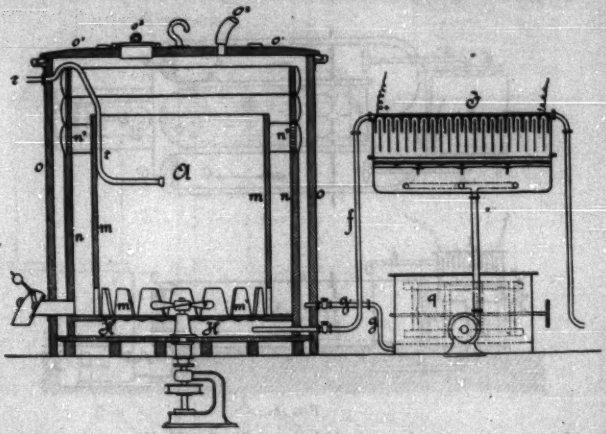

FIG. 7.

tion the essential principles of the machine just described, is shown in *Fig.* 7. Here are three tubs, or vats, one within the other, and in the center of the bottom is placed a propeller, or mixer, intended to thoroughly agitate the contents. Connected with these vats, and conveniently placed, is an electrolyzer, fitted with a pump, by which it is caused to deliver a volume of freshly electrolyzed liquor, and, at the same time, to receive an equivalent volume of spent, or partially exhausted, solution. Here is shown the arrangement constructed for continuous working, and where the

highest chemical and mechanical economies appear to be completely realized.

Naturally, the main issue involved in the whole subject of the technical application of electricity to textile bleach-

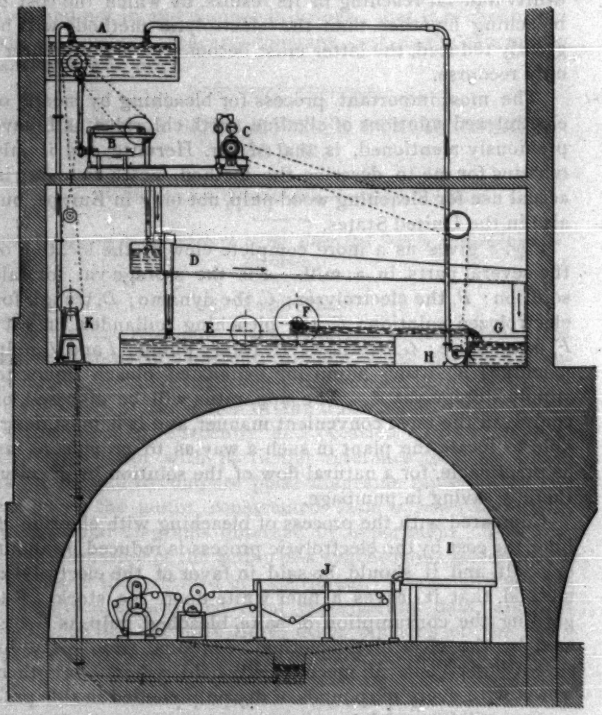

FIG. 8.

ing, resolves itself into the question: Can a process which involves the use of such seemingly elaborate apparatus compete successfully on the commercial scale with the chloride of lime process? and I answer, yes. I am prepared to

go even farther, and to affirm my full conviction that the electrolytic method will be found to afford our manufacturers the only means of meeting trade competition, and that, unless there be made some chemical discovery of very great utility and far-reaching in its results, by which the cost of bleaching by other than the electrolytic methods will be greatly reduced, the latter must become the manufacturer's only recourse.

The most important process for bleaching by means of electrolyzed solutions of alkaline earth chlorides, as I have previously mentioned, is that of Mr. Hermite, and it only remains for me to describe the method, which is to-day in actual use for bleaching wood-pulp, not only in Europe, but also in the United States.

Fig. 8 gives us a more complete view of the location of the several parts in a mill. *A* is the storage-vat for salt solution; *B*, the electrolyzer; *C*, the dynamo; *D*, trough for electrolyzed solution; *E*, the bleaching hollander, or vat; *F*, drum sieve; *G*, overflow; *H*, rotary pump; *I* and *J*, pulp machine; *K*, lifting pump for exhausted bleach liquor to supply storage-vat *A*. The apparatus will be disposed, of course, in the most convenient manner, and it is most desirable to locate the plant in such a way as to provide, as far as practicable, for a natural flow of the solution by gravity, thereby saving in pumpage.

Compared with the process of bleaching with chloride of lime, the cost by the electrolytic process is reduced by about one-half, and it should be said in favor of the electrolytic method, that it leaves a finer white upon the stock. Regarding the consumption of salts, bleached pulp, as delivered by the electrolytic method, contains from sixty to seventy per cent. of mechanically-held water. In other words, with every 100 pounds of dry pulp yielded in this process, we will have withdrawn from 150 to 230 pounds of water, which will have contained in it a certain amount of dissolved salts, and which will have to be replaced in the partially exhausted bath before being re-electrolyzed. Carrying our comparisons further, we see that the bleacher has at his command a process whereby he can obtain an effective

bleaching agent at a moment's notice, and without requiring extensive changes in his present plant; that the bleaching agent so produced is free from any residue or sediment; that it is much more complete in its bleaching action than chloride of lime; that the action on the fibres is rapid, regular, and not in any manner injurious; that it is cheap, and with a constant, or nearly constant, cost, as the raw materials are low in price.

ACTION OF A SINGLE-PHASE SYNCHRONOUS MOTOR.

By Frederick Bedell and Harris J. Ryan.

[*Communicated by the authors to the Electrical Section of the Franklin Institute.*]

INTRODUCTION.

The phase relations of the different variable quantities in any alternating current problem are of paramount importance, and have often been the subject of investigation in the study of the action of the transformer. The writers of this paper have recently had occasion to study the synchronous motor with particular reference to these phase relations, and to compare polar diagrams representing the action of the motor, constructed from *a priori* reasoning, with similar diagrams obtained by experiment. The complete discussion of the action of a synchronous motor which follows, is thus verified by experiment. The polar diagrams here given, constructed from experimental data, are now published for the first time; other portions of the work have already been published in some preliminary papers,* parts of which are here included *verbatim*. The experimental

* "The Behavior of Single-Phase Synchronous Motors," by H. J. Ryan; *Sibley Journal of Engineering*, vol. viii, No. 8, May, 1894.

"An Optical Phase Indicator and Synchronizer," by G. S. Moler and F. Bedell, a paper read before the American Institute of Electrical Engineers, May, 1894; *Transactions*, vol. xi, p. 586.

"The Behavior of Single-Phase Synchronous Motors," by C. E. Hewitt and J. Lyman; *Sibley Journal of Engineering*, vol. viii, No. 9, June, 1894.

work was performed in the spring of 1894, under the direction of the writers, at Cornell University, by Messrs. J. Lyman and C. E. Hewitt, who have already published a partial report of the investigation in one of the papers already referred to.

We will first discuss the action of a synchronous motor, and will then describe the method of conducting the present investigation.

THE SYNCHRONOUS MOTOR.

The action of the commutator on a direct-current dynamo is to rectify the current induced in the armature; that is, the current from the dynamo after it leaves the brushes flows continually in one direction, although the current in the armature coils is being constantly reversed. The commutator of a direct-current motor performs the converse function. Let us suppose that we have two similar machines of this kind separately excited, and that the one is driving the other as a motor. If it so happens that the two armatures are revolving at the same speed, the two commutators may be done away with, for it is evident that the rectifying of the current by the dynamo commutator is counterbalanced by the corresponding reversal of the current by the motor commutator. The current in the coils of the motor armature flows alternately in opposite directions corresponding exactly to the flow of current in the dynamo armature. We see, then, that when the motor and dynamo are running synchronously the armature circuits may be directly connected without any commutators; that is, we have an alternating current generator driving an alternating current synchronous motor. The operation of a synchronous motor was first described by H. Wilde in a paper* read before the Literary and Philosophical Society of Manchester, December 15, 1868. The inherent regulation which maintains synchronism was referred to in this paper.

The significance of these observations was not felt at

* "On a Property of the Magneto-electric Current to Control and Render Synchronous the Rotations of the Armatures of a Number of Electro-Magnetic Induction Machines;" *Philosophical Magazine*, January, 1869.

the time, and some years later Dr. J. Hopkinson,* unaware of the earlier work, developed the analytical theory for the operation of two alternating current machines, his conclusions as to synchronous control agreeing with the observations of Wilde.

Although any alternating current generator will thus operate as a synchronous motor, it is not true that they will all thus operate equally well. The old smooth-bodied armature alternator,† with "pan-cake" armature coils, made a very poor synchronous motor, while the modern alternator, with "T-toothed" armature, fitted with machine-wound armature coils, has been found to give excellent results when run as a synchronous motor. This improved performance of the alternator as a synchronous motor is due to the increased self-induction of the armature and to the useful effects of the armature current on its own field. When the current developed by a generator is in unison with the generated E.M.F., such current exerts very little effect upon the field—neither strengthening nor weakening it. When the current lags behind the E.M.F. of the generator, the armature reaction effect that it produces upon the field is such as to weaken the field, and thus to diminish the E.M.F. produced by the generator. The reverse of this action occurs when the generator furnishes a current that is in advance of its E.M.F. This is shown to be true in the experiments which follow by the gradually increasing values of generator E.M.F. (given in the tabular data in the latter part of this paper), as the current, which at first lags behind the generator E.M.F., is brought into phase with it and

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* "On the Theory of Alternating Currents, Particularly in Reference to Two Alternate-Current Machines Connected to the Same Circuit;" *Jour. Soc. Telegraph Engineers*, vol. xiii, p. 496, 1884. At the same meeting was read and discussed a paper on "The Alternate-Current Machine as a Motor," by W. G. Adams. Further references relating to the development of the synchronous motor are given by W. M. Mordey, in his paper on "Alternate-Current Working;" *Jour. Inst. Elect. Engineers*, vol. xviii, p. 592, 1889. See also, "Long-Distance Transmission for Lighting and Power," by C. F. Scott; *Transactions Am. Inst. of Elect. Engineers*, vol. ix, June, 1892.

† We here closely follow the first paper above referred to: *Sibley Journal*, May, 1894.

finally into a position of advance. Precisely the same armature reactive effects on the field occur in a synchronous motor. There is this exception, however, that the motor E.M.F. is counter to that of the generator, so that what is a lagging current for the generator is an advance current for the motor, and the current that is in advance of the generator E.M.F. lags behind the counter E.M.F. generated by the motor. The current that strengthens the field of the generator will thus weaken the field of the motor, and *vice versa*, as will be explained later.

The speed, as is well understood, depends only on the periodicity produced by the generator and the number of poles of the motor. Neither variation of the E.M.F. impressed at the terminals of a synchronous motor, nor variation of its field excitation, will change the resulting speed so long as the motor operates at all. The armature circuits of the motor, generator and line always possess some self-induction. When, therefore, the generator pressure is higher than that of the motor at the moment when synchronism is obtained, and the machines are connected, a current will pass between the machines that will lag, because of the self-induction, behind the generator E.M.F., and will be in advance of that of the motor pressure. This current, as was just pointed out, will weaken the field of the generator and lower the E.M.F. that it generates; it will strengthen the field of the motor, and in proportion will raise its counter E.M.F. The result, therefore, is to equalize the developed pressures of generator and motor, and thus prevent a further increase of current. Such a current will have a larger component in unison with the generator pressure than with that of the motor, depending on the proportion of the electrical energy transformed into mechanical energy.

The diagram, *Fig. 1*, illustrates the action of a synchronous motor that develops a motor pressure E', equal to the generator pressure E. In this, and in all the diagrams following, positive rotation is counter-clockwise. In the case of *Fig. 1*, the circuits are assumed to have no self-induction, but to have the usual resistance. At the instant that syn-

chronism is obtained and the connection of the motor completed, there can be no current established through the motor, and, therefore, no power developed. The motor will lag in rotative speed at once to some such position as *d*, where the resultant of the motor and generator pressures is *ac* or *E''*. Since there is no self-induction in the circuit, the resulting current, *I*, is in unison with *E''*. Such a current has component values in unison with the generator and motor pressures that are equal. No power can, therefore, be developed, and the motor would promptly come to a standstill.

The conditions represented by *Fig. 2*, are, that the generator pressure is greater than the motor pressure, and that the circuits possess resistance but no self-induction. At the moment that the motor is synchronized and connected, a current will be established that is in unison with the generator pressure and opposite to that developed by the motor. The developed power that thus results is, in general, more than sufficient to keep the motor running light at synchronism. The speed position of the armature is, therefore, advanced to a point *d*. Here is obtained a resultant E.M.F., *E''*, that, since there is no self-induction, establishes a current which is in unison with the resultant E.M.F., *E''*. The component *ae* along *E* is here greater than the component *af* in the direction of the motor E.M.F., *E'*. A balance occurs at that point where the power developed is just sufficient to keep up the synchronous speed of the motor armature, and no further acceleration takes place. On loading down the motor its armature position is retarded. The maximum load that the motor will stand is that at which the product of the motor pressure into the component of the current that is in unison with it, is a maximum. This the diagram plainly indicates to be at the point of true synchronism. When this point is reached an increase in the load will further retard the armature, and the above product will again diminish; the motor, being overloaded, will come quickly to rest.

In *Fig. 3*, *E* and *E'* are equal, the armature and line circuits have no appreciable resistance, and self-induction is

present. At the instant of synchronism and connection of the motor to the generator circuit, no current will be established through the motor, because the generator and counter E.M.F.s are equal. The motor armature will lag to a point where the resultant pressure is E''. E'' will establish a current I, one-quarter of a period behind itself. Such a current will have a large component that is negative with respect to the motor pressure and in unison with that of the generator. An early point is reached at which the motor will do good work. Later on a maximum component of this current, that is opposite to the motor pressure, will be found, beyond which the motor will lose synchronism.

In *Fig. 4*, the generator E.M.F., E, is greater than the motor E.M.F., E'. The circuits possess self-induction, but no resistance. At the instant that the motor is synchronized and connected, the resultant pressure, E'', is the algebraic difference between E and E'. Inasmuch as the circuit possesses self-induction with no resistance, E'' will establish a current through the motor at right angles to itself and the motor and generator pressures. From such a current no power can result. The armature will lag to a later position, where the conditions are found to be practically the same as those discussed in connection with *Fig. 3*.

In *Fig. 5*, E equals E', and resistance and self-induction are both present in the circuits. Since E and E' are equal, no work can be done until the armature lags to some position, d, where the resultant E.M.F. is E''.

When the E.M.F., resistance, self-induction, and periodicity of a circuit, are known, the impedance is known, and the current becomes known from the relation

$$\text{Current} = \frac{\text{Resultant E.M.F.,}}{\text{Impedance}}$$

The phase position of the current is determined by the relation between the resistance and the reactance of the circuit. The projection of I upon E' is a quantity that is proportional to the developed mechanical power. This projection, as in all other cases, at a certain position attains a maximum beyond which the motor will come to rest.

In the next diagram, *Fig. 6*, E is greater than E', and self-induction and resistance are present. In general, the position of the armature at no load will be in advance of the normal position of synchronism, the position of advance being limited, as in the similar cases cited above, and which the figure fully illustrates.

In practice, the relations of the magnitudes of E and E' are determined by the field excitation and the currents that are established through the motor. Armatures that develop powerful reactive effects upon their fields, in action equalize the motor and generator pressures, and such armatures must necessarily possess considerable self-induction. These are the requirements for suitable working, as indicated by the above analysis.

It is well to suggest, also, that the amount of the mass of the revolving parts of a synchronous motor has an additional effect upon the stable operating conditions. During every complete period, there are two short intervals, throughout which the motor, in general, must act as a generator and give back a small amount of power to the generator. The only source of this power is the fly-wheel property of the revolving parts of the motor. Multiphase motors are independent of this fly-wheel effect, because at no instant does the motor do work on the generator, while on the other hand, the amount of mechanical energy developed instant after instant is practically uniform.

THE PHASE-INDICATOR.

In the experimental investigation of the synchronous motor, the Bedell-Moler phase-indicator* was employed to determine the angular difference in the position of the armatures of the motor and generator. The shafts of the motor and generator were placed in line, abutting, but not quite touching. The phase-indicator consists of two metal disks, each fastened to a collar made to slip on the adjacent ends of the two armature shafts, and held in position by

* *Loc. cit.*

set-screws. These disks are of zinc, one-thirty-second of an inch thick, nine inches in diameter, and about one-quarter of an inch apart. In the disks are curved slits, about one-twentieth of an inch wide, extending from points near the hub almost to the circumference. In this case—the motor and generator having eight poles—there were four slits in each disk, one slit corresponding to each pair of poles, or to the number of complete periods in one revolution. The direction of curvature of the slits in one disk is opposite to that in the other, so that the slits of one cross those of the other; otherwise, the two disks are in every way similar. The intersection of the slits forms an opening that will allow a beam of light from an incandescent lamp, placed at one side, to pass through. Each slit extends over a complete period, from its inner to its outer end; therefore, one of the armatures must move, with reference to the other, through a complete period, to cause a spot of light to travel through this range. *Fig. 7* makes this more clear. If the two armatures are revolving at the same speed, or synchronously, the intersections of the slits remain at a fixed distance from the center, and we see, in consequence, a ring of light. If one revolves faster than the other, the ring of light moves either towards the center or towards the circumference of the disk. These slits are so constructed that the distance to or from the center, traversed by the intersections of the two sets of slits, is proportional to the change in the relative angular positions of the two armatures.

The curvature of the slit is that of the spiral of Archimedes, and was constructed as follows: Each quadrant was divided into eighteen equal sectors. Nineteen concentric circles were then drawn with a sharp tool on the face of the disk, thus dividing the portion of the disk lying between the extreme limits desired for the slit, into eighteen annuli, each about three-sixteenths of an inch wide. The slit represents a complete period of 360°; therefore, the widths of the sectors and annuli represent 20°. The points of intersection of the corresponding radii and circles give the location of the slits.

The position of the ring of light indicates the relative positions of the two armatures. This position was observed in a mirror set at an angle of 45° with the plane of the disks, and arranged with a scale reading in degrees corresponding to the scratched circles on the disk. An observer could thus see, in the mirror, the reflected ring of light and the phase position which it indicated. The disks were set so that the outer ends of the slits were adjacent when the two armatures stood on their corresponding neutral points, the positions being determined by the ballistic galvanometer method of field exploration. With the armature on the neutral point, no throw of the needle of a ballistic galvanometer connected to the brushes is obtained, when the field current is reversed.

In operation, the ring of light shown by the phase-indicator would vibrate, more or less, according to the stability of the motor. This vibration was small, when the motor was operated under the most favorable conditions; but with unstable conditions, it would vibrate, at times, as much as 30° on each side of the mean, before the motor would go out of synchronism.

The present investigation has shown the phase-indicator to be, in all respects, an efficient instrument.

THE GENERATOR AND MOTOR.

Two small Westinghouse alternators, of the same size and shape, designed to supply ten incandescent lamps, were used as generator and motor. Before being thrown into direct connection with the generator, the motor was brought to speed by means of a direct current-starting motor, to which it was belted. A half horse-power Edison machine was used for this purpose. When synchronism was reached, the direct current supplying this starting motor was broken at the instant that the alternate current motor was connected to the generator.

The magnetization curve for the alternate current motor was found to be practically a straight line, as shown by the following readings, which are corrected for a normal speed of 2,080 revolutions per minute:

DATA FOR MAGNETIZATION CURVE OF MOTOR.

Current in Motor Field.	E.M.F. at Brushes.	Speed.
1·	9·9	2,080
1·5	16·7	"
2·	22·7	"
2·5	28·7	"
3·	34·5	"
3·5	40·5	"
4·	46·4	"

The stability of a synchronous motor depends largely upon the field excitation and the amount of the self-induction in the armature circuit. With no added self-induction in the armature circuit the motor in the present case was found to be quite unstable. Curve *A*, *Fig. 8*, shows the relation between the current flowing through the motor and generator armatures and the exciting current of the motor field, when no added self-induction was in the armature circuit. The motor was driving the small Edison machine on open circuit as a light load. The generator field excitation was kept constant at 3·5 ampères; the speed was 2,080 revolutions per minute. The extreme range through which the motor could be kept in synchronism was from a motor field current of from 1·5 to 3·3 ampères. With a motor field excitation of 3 ampères, the armature current was a minimum. The operation under these conditions, however, was quite unstable, and a light load would throw the motor out of synchronism, and thus cause it to stop.

The stability was increased by the addition of self-induction to the armature circuit, and for this purpose a coil without iron was employed. Curves *B* and *B'*, *Fig. 9*, show the relation between the motor excitation and armature current, as was shown by curve *A*, for the preceding case without added self-induction. The motor ran synchronously with a field excitation varying from ·6 to 2·2 ampères, and from 3 to 3·6 ampères, but would not run with an exciting current between 2·2 and 3 ampères. With the weak field excitation, a large current was consumed by the motor, while with the strong excitation current, a much smaller current was taken by the motor. This may be attributed to the phase position which the current takes in the two cases, with reference to

the phase position of the impressed E.M.F., as is shown by the polar diagrams for such cases.

It was found that by gradually increasing the self-induction in the armature circuit, the two parts of the curve *B* and *B'* were brought together. The self-induction was increased by inserting in the coil an iron core consisting of a bundle of iron wire. At a certain position of this core the self-induction of the armature circuit was such that the motor consumed a much smaller current than at any time before, ran with great stability, and through a wide range of field excitation, as shown by curve *C*, *Fig. 10*, which will be discussed later. The final run was made under these conditions.

The coëfficient of self-induction of the motor armature was found to be 0·00032 henrys, and that of the induction coil with the iron core, 0·00168 henrys. The total self-induction was, therefore, 0·002 henrys. The total ohmic resistance of the armature circuit and connections measured 0·31 ohms. The self-induction of the armature was measured for different field excitations and for different currents, the mean of all the values obtained being averaged and taken as constant. The excitation of the field seemed to make no appreciable difference in the coëfficient of self-induction of the armature. The resistance and self-induction of the armature circuit vary somewhat with the value of the current flowing, on account of temperature changes and the saturation of the iron, but the error introduced by considering these constant is small. From these measurements the reactance and impedance were determined.

THE METHOD OF EXPERIMENT.

Throughout the following investigation, the generator was run at a nearly constant speed of about 2,080 revolutions per minute, and with a constant field excitation of 3·5 ampères. The motor was brought up to speed by the small Edison starting motor mentioned above, and thrown into circuit at the instant when its phase position, as indicated by the ring of light of the phase-indicator, remained 180° behind that of the generator. The small Edison machine

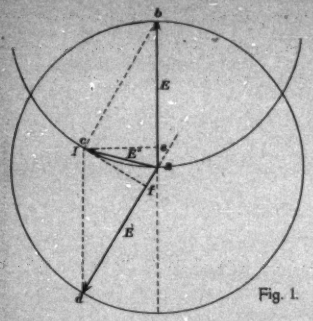


Fig. 1.

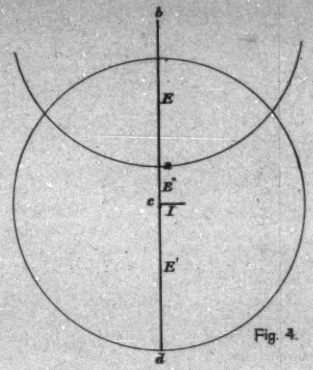


Fig. 4.

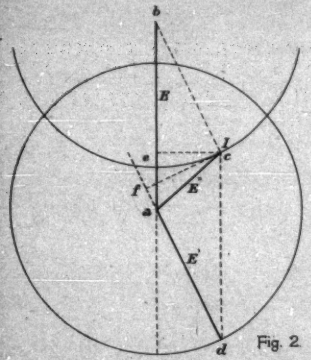


Fig. 2.

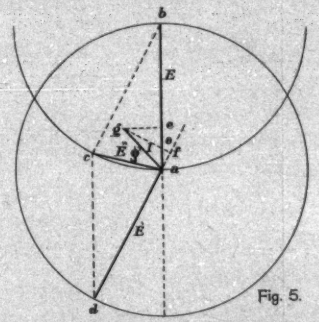


Fig. 5.

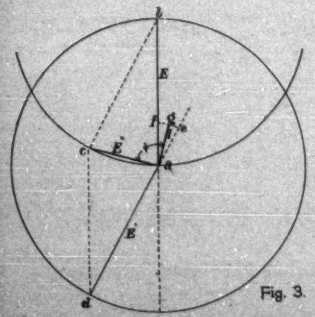


Fig. 3.

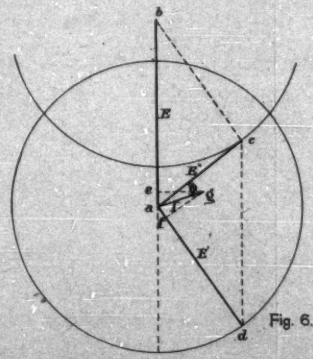


Fig. 6.

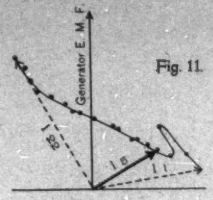


Fig. 11.

Locus of the direction and magnitude of the armature current.

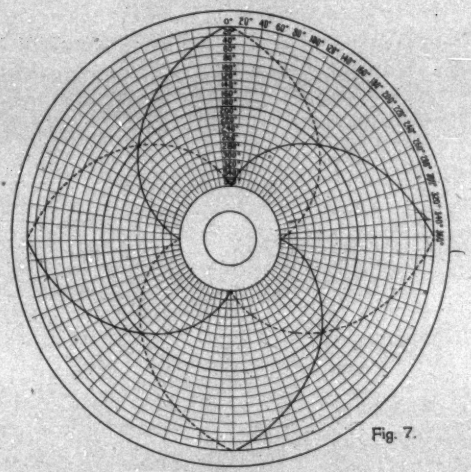


Fig. 7.

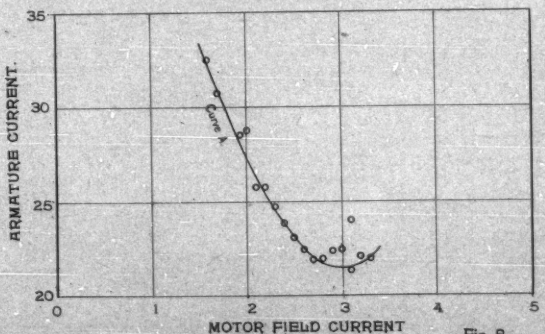


Fig. 8.

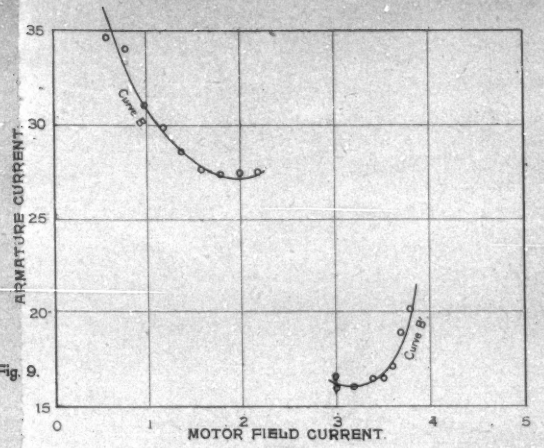


Fig. 9.

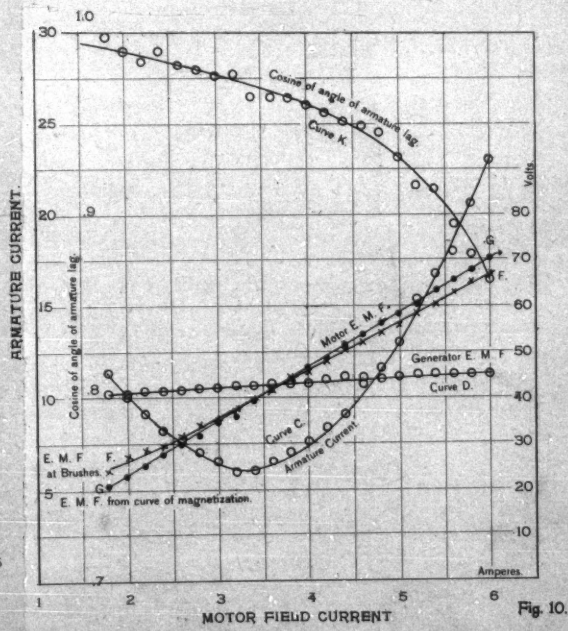
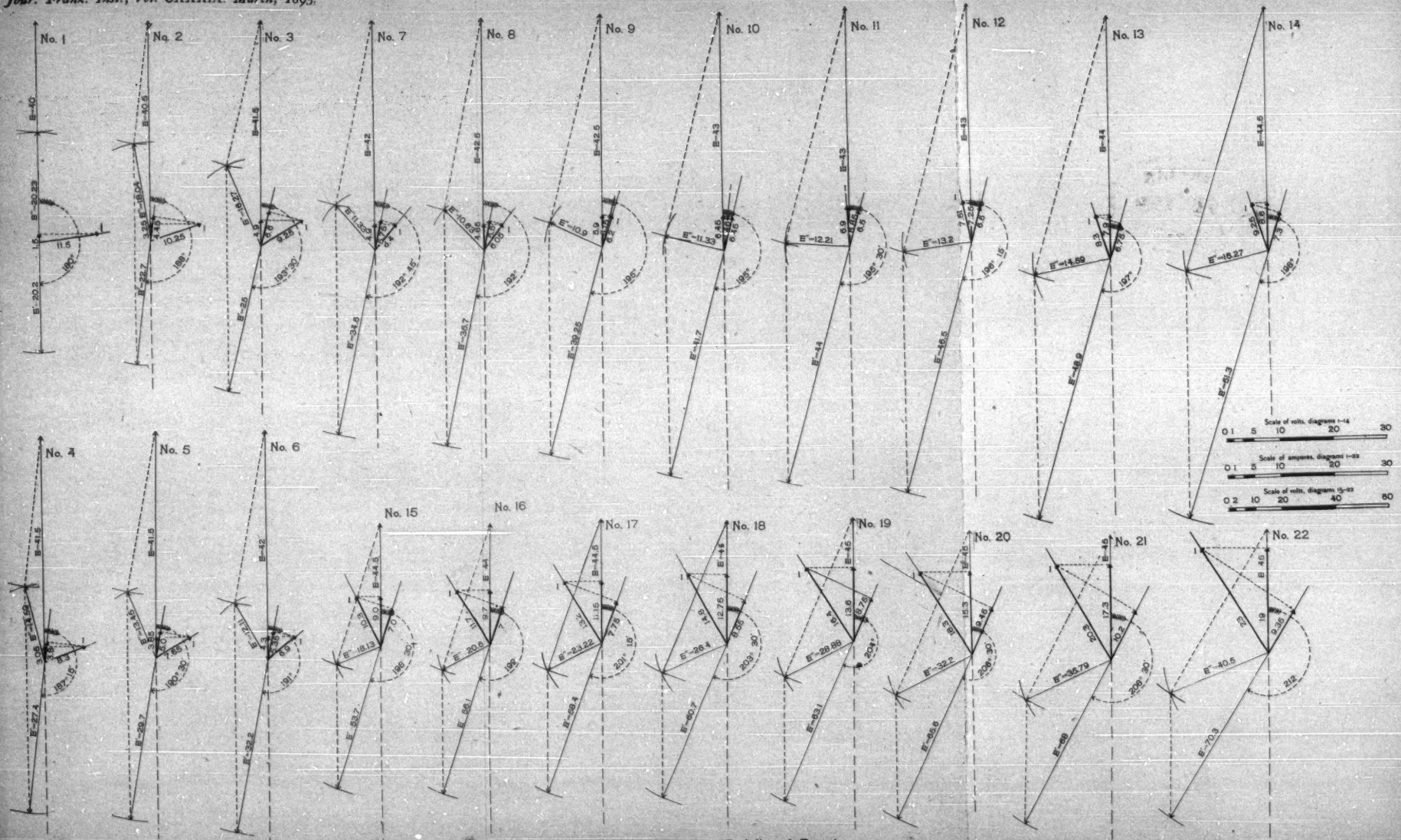


Fig. 10.

THE SYNCHRONOUS MOTOR (Bedell and Ryan.)



SYNCHRONOUS MOTOR DIAGRAMS. (Bedell and Ryan.)

was then driven on open circuit as a light load for the alternate current motor, this being the only load throughout all the experiments here described. The exciting current of the motor field was changed by increments of 0·2 ampères between the limits 1·8 and 6 ampères. The motor and generator field currents were obtained from a storage battery, and were accordingly quite constant.

The quantities required were:

The impressed E.M.F. (E) of the generator;

The counter E.M.F. (E') of the motor;

The resultant E.M.F. (E''), which is the resultant of the impressed and counter E.M.Fs;

The armature current (I''');

The angle of lag (ϕ) of the current behind the resultant E.M.F. (E''); and

$$2\pi \times \text{frequency} = \omega = \frac{2\pi \times 4 \times \text{r.p.m.}}{60}$$

The above quantities are required in order to construct the graphical diagrams which show the complete action of the synchronous motor.

The following quantities were likewise obtained:

Generator field current (I').

Motor field current (I'').

Disk reading, angle ϕ.

The currents were measured directly by means of a Siemens' dynamometer. The impressed E.M.F. (E) of the generator was obtained from a voltmeter connected to the generator brushes. The counter E.M.F. of the motor was taken directly from the magnetization curve for the motor plotted according to the table given above, no correction being made for armature reactions.

The electromotive forces E, E' and E'' must all be in equilibrium when the motor is running. The motor, when running in synchronism, will take such a phase position with respect to the generator that this relation is obtained. The resultant E.M.F. (E'') is then just sufficient to overcome the product of the current (I''') and the impedance of the armature circuit. Therefore:

$$E'' = I''' \times \text{impedance.}$$

The E.M.F. is thus computed: The angle of lag of the current behind the resultant E.M.F. is

$$\phi = \text{arc tan.} \frac{\text{reactance}}{\text{resistance}}.$$

The resistance and self-induction being taken as constant, we have, therefore, a constant value for the angle ϕ, viz.: 82·5° (the speed varying little during the run, and ω being taken, therefore, as constant).

The phase position of the motor with respect to the generator is represented exactly by the phase positions of their respective E.M.F.s. The relative phase position of these E.M.F.s was determined by graphical construction, as in *Fig. 5*. The generator and motor E.M.F.s and their resultant being known, their position is determined by a construction analagous to the parallelogram of forces. In *Fig. 5*, *ab* represents the direction and magnitude, taken in any convenient scale, of the generator E.M.F.; *ad*, the motor E.M.F., as taken from the magnetization curve; *ac*, the resultant E.M.F. The magnitudes of the E.M.F's. being known, their relative positions are thus determined. The angle between the resultant E.M.F., *ac*, and the current, being determined as described above, *ag* may be drawn to represent the current. The diagrams, Nos. 1–22, are thus constructed:

The angle *bad* measured backward (or clockwise) shows the phase position of the motor armature with respect to the generator armature, and it should agree substantially with the disk reading of the phase indicator.

The energy in watts delivered by the generator to the circuit is equal to the product of the impressed E.M.F. (E) and of *ae*, which is the component of the current *ag* in line with the impressed E.M.F.

The energy in watts transformed into mechanical power by the armature is equal to the product of E' and of *af*, the component of the current *ag* in line with E'. This product must be negative in value, showing energy consumed and not produced, for the machine to run as a motor. The mechanical power developed is expended in driving the Edison machine on open circuit, and in journal friction, hysteresis and

foucault currents. The iron losses increase as the field excitation is increased. The difference between the watts delivered and the watts transformed into mechanical power is equal to the RI^2 losses of the armature circuit. Thus, from the fifth observation (see Diagram 5), we have:

Watts input = 41·5 × 3·85 = 160.
Watts mechanical power = 29·7 × 5·0 = 148.
The RI^2 losses = 160 — 148 = 12 watts.

In the accompanying table, the observed data are given to the left of the double line, and the computed results to the right. No measurements were made with a motor field current above six ampères, on account of the possibility of springing the armature shaft; it is to be supposed that the motor would run synchronously beyond this point.

The results given in the table are likewise shown in *Fig. 10*, and in the diagrams Nos. 1-22. In *Fig. 10*, curve *C* shows the armature current for different field excitation; the current becomes less and less as it comes into phase with the impressed electro-motive force, and then increases as it takes a position in advance of the electro-motive force. That there is a point of minimum current and a maximum power factor was shown by Mr. Mordey, in a paper read before the Institution of Electrical Engineers,* in which he gave a curve for the armature current at light load, such as curve *C*, *Fig. 10*. He further showed that the motor E.M.F. could be higher than the generator E.M.F., as is clearly brought out by the present paper. This point was predicted in 1884 by Dr. Hopkinson in his paper† before the Institution of Electrical Engineers, on "The Theory of Alternating Currents." In the discussion, Mr. Kapp‡ showed such curves for several loads, showing the forms these curves would take, both with and without armature reactions. His curves were plotted with abscissæ representing the counter E.M.F. of the motor. The counter E.M.F.

* "On Testing and Working Alternators," *Journal of the Institution of Electrical Engineers*, Feb. 23, 1893; see also London *Electrician*, Vol. xxx, p. 545.

† *Loc. cit.*

‡ London *Electrician*, Vol. xxx, p. 575.

Number of Observation.	F, Generator Field Current.	F', Motor Field Current.	I''', Main Current.	E, Generator E.M.F.	E.M.F. at Motor Brushes.	Reading of Phase Indicator: Angle θ.	Speed.	E', Motor E.M.F.	E'', Resultant E.M.F.	Computed Angle θ.	Watts Input.	Watts Transformed into Mechanical Power.	RI^2 Losses of Line and Motor Circuit in Watts.	Computed RI^2 Losses in Watts.
1	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
2	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
3	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
4	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
5	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
6	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
7	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
8	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
9	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
10	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
11	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
12	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
13	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
14	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
15	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
16	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
17	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
18	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
19	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
20	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
21	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
22	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
23	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
24	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
25	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
26	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
27	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
28	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
29	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
30	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
31	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
32	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
33	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
34	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114
35	3.35	2.80	11.5	405	114	69°	0.988	405	1340	18°	1310	1200	110	114

OBSERVED. COMPUTED.

of the motor was not directly proportional to the exciting current, for his curve of magnetization was not a straight line. Mr. Steinmetz* has determined these curves analytically, plotting them from a quartic equation showing the relation between armature current and motor E.M.F. He assumes a constant reactance and the absence of armature reactions. His theoretical curve for no load (where no load means the absence of friction and of all energy expenditure) meets the X-axis at a sharp point, which would show that when the motor was doing absolutely no work, the armature current would actually be brought to zero, for a particular value of the field current. His curve for light load corresponds approximately with curve *C*. It is, however, constructed for a constant load, whereas the load in the present investigation became greater as the hysteresis losses increased with the excitation.

The increase in the generator E.M.F. on account of armature reactions, although the speed and excitation were constant, is shown in curve *D*, *Fig. 10*. That armature reactions have the opposite effect in the motor, as mentioned earlier in this paper, is shown by curves *F* and *G*, which represent, respectively, the E.M.F. observed at the brushes of the motor, and that obtained from the curve of magnetization. With a small field excitation, the armature current, which is a lagging current with reference to the generator E.M.F., is one of advance with reference to the motor E.M.F.; and the armature reactions are, therefore, such that the E.M.F. at the brushes of the motor is greater than that obtained from the curve of magnetization. With a larger field excitation of the motor, the armature current is one of advance with reference to the generator E.M.F., and a lagging current with reference to the motor E.M.F., which causes the E.M.F. at the brushes of the motor (curve *F*) to be less than that obtained from the magnetization curve, as shown in curve *G*. The rise in the generator E.M.F., due to armature reactions, corresponding to this decrease in

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* "Theory of a Synchronous Motor," *Transactions of the American Institution of Electrical Engineers*, Oct. 17, 1894.

motor E.M.F., due to the same cause, is shown in curve *D*, as already explained. These curves have not been corrected for the fall of potential due to the impedance of the armature; but the results are quite striking and are in accordance with the explanation given in the early part of this paper, to the effect that the armature reactions in the generator and motor assist in the self-regulation of the plant. The gradual change in armature lag is shown by curve *K*.

Diagrams, Nos. 1–22, are drawn for each corresponding set of readings given in the table. The current, represented by the heavy arrow *I*, lags behind the generator E.M.F. when the field excitation of the motor is weak. The motor thus produces the effect of self-induction in the circuit.

As the excitation is increased, the current comes more and more into phase with the E.M.F., and finally comes into phase with it. The armature current is now a minimum. A further increase in the field excitation advances the armature current ahead of the E.M.F.; that is, the motor now acts the same as a capacity, or condenser, in a circuit, this capacity-effect increasing as the field excitation increases.

In a recent paper* on "Some Advantages of Alternate Currents," Prof. S. P. Thompson lays particular stress on this condenser action of an over-excited synchronous motor, and emphasizes the fact that synchronous motors may advantageously be operated in parallel with transformers, to overcome the effects of self-induction. We have experimented at length upon the action of condensers in parallel with transformers,* and the advantages to be obtained by this system of operation. Inasmuch as the transformer tends to make the current lag, and the condenser tends to place the current in advance of the E.M.F., it is possible to obtain such a balance between the two that the line current will be in phase with the electro-motive force. Under these circumstances a certain amount of power is transmitted

* British Association, Oxford, 1894.

* See Hedgehog Transformer and Condensers, *Transactions of Institute of Electrical Engineers*, Vol. x, p. 497.

with a minimum current. The polar diagrams, in the present paper, show conclusively that the condenser action of over-excited synchronous motors will enable them to be operated in the same way as were the condensers in the paper referred to.

The changes in the magnitude and direction of the armature current, as the field excitation changes, are clearly seen in *Fig. 11.* The current for the first observation (compare Diagram 1) for the weakest field excitation, has the position I_1. As the field excitation increases, it takes successively the positions indicated by points, coming into phase with the E.M.F., and finally in advance of it, as shown in the position I_{22}, corresponding to the last observation (see Diagram 22). The heavy arrow I_8 represents the current for one particular observation. The locus for the armature current is obtained by drawing the curve through the successive points. With a constant E.M.F. the distance of any point of this curve above the horizontal would be proportional to the power given the motor. With a constant E.M.F. and constant power supplied to the motor, the curve would be a horizontal straight line. The rise in the curve at the left is due to the increased power, necessary in this case as the field current of the motor is increased. The irregularity in the curve at the right is due to the instability of operation during the first few observations.

In constructing the polar diagrams, the values of θ, the angle of lag of the motor armature, as obtained by the readings of the phase-indicator, were not employed. From the diagrams constructed as described above, the value of the armature lag was obtained as given in the column headed "Computed Angle θ," which is seen to agree closely with the armature lag as shown by the phase-indicator. The accuracy of the work and the correctness of the reasoning were thus completely verified by the phase-indicator readings.

The polar diagrams, here shown for the first time, thus simply show the complete action of the synchronous motor.

CORNELL UNIVERSITY, December, 1894.

WATER PURIFICATION.*

By Rudolph Hering.

[*Concluded from p. 144.*]

We now come finally to the process of purification by *filtration*, which is more effectual than any of those hitherto mentioned in effecting a permanent removal of the impurities. It allows the water to pass through a porous material which, first, on account of the straining action of its pores, frees it from suspended particles which have made it turbid. Then, owing partly to a chemical purification and partly to the action of living bacteria, the dissolved organic matter is transformed into nitrates or mineral compounds. This transformation is effected by reason of the large interstitial area existing in the many pores of the filtering material.

We may divide the processes into two classes: those where the filtration is *rapid*, and those where it is *slow*. In the former case we obtain merely a clarification of the water, because a certain time and special conditions are necessary to allow of a complete destruction of the organic matter by the filter, which conditions are fulfilled only by slow filtration.

In the case of *rapid* filtration, the pores are continually filled with water flowing through them under more or less pressure. When the pores are of nearly equal size, as for instance in the Pasteur filter, or in filters made of certain other artificially prepared materials, there obtains a nearly fixed relation between the amount of clear water produced and the pressure exerted upon the filter. But where the pores are of unequal sizes, an increased pressure is apt to force out the retained substances from the smaller into the larger pores, and thus, to some extent, to allow them to escape and leave the water in a less clear condition. Filters of natural gravel, where the pores are of different sizes, have

* A lecture delivered before the Franklin Institute, February 2, 1894.

been known to run quite turbid for a while after the pressure upon them has been increased. The degree of clearness depends upon the degree of fineness of the pores, and the finer the pores the greater will be the pressure necessary to deliver the same quantity of clear water.

We have, therefore, a fixed relation between the degree of clearness of the water, the fineness of the material, the pressure of the water when passing through the filter and the quantity of clear water delivered by it. The action of rapid filtration is almost wholly mechanical, so far as practical purposes are concerned.

The first action of a filter is to retain the coarse particles of suspended matter upon the surface. Some of them enter the pores for a short distance and these particles themselves, when lodged, act as a filtering material and assist in straining out the finer particles. The most effective part of the filter is, therefore, that near its surface.

The accumulation of the finer particles gradually causes the filter to become obstructed; and, if the filter is to remain efficient, these retained particles must be periodically removed. The depth of material necessary for efficient filtering depends on its fineness; the finer it is, the shallower the filter may be.

The pores of a filter are not fine enough to remove the bacteria by straining. In all systems of rapid filtration they are retained only by a film which is gradually formed on the surface of the filter, either by the accumulation of organic matter or by a coagulant in the water. As it always takes some time for this film to form, and as its continuity can readily be destroyed at any time, it offers no security against the possible reappearance of a large proportion of the bacteria in the effluent water.

Regarding the materials which are used for rapid filtration we may classify them as being fibrous, granular and porous.

The fibrous material used for filters consists of felt, cloth, straw, cotton, or the like. The use of sponges is also common. Mineral wool made of fine spun glass is likewise used.

The granular materials are such as sand, gravel, finely-broken stone, charcoal, coke, cinders, and some artificial materials for which special advantages are claimed.

Porous material may be unglazed porcelain, burnt clay, certain volcanic minerals, or some artificial product. But porous stone soon becomes clogged, and then it is almost impossible to clean it. It is useful only when its pores are very fine, so that the matter which is strained out is kept so near the surface that it can be removed by washing.

Some filtering materials act also chemically upon the matter which is dissolved in the water; for instance, animal charcoal will absorb gases, such as oxygen, nitrogen, carbonic acid and sulphuretted hydrogen, and will remove some mineral salts. It will also destroy some of the albuminous compounds, as is proven by the fact that free ammonia and nitrates are found in the effluent water. Both of these are formed by decomposition while the water is passing through the charcoal. Charcoal is known to be more effective than sand in removing dissolved substances, particularly at first, and also in removing coloring matters contained in the water. But it is not as permanent in its operation, and its efficiency ceases in time.

Experiments made with fine charcoal and coke for rapid filtration, show that besides acting as a strainer, and besides having a very slight chemical action, they have removed, for several days at a time, over ninety-five per cent. of the bacteria contained in the water. They are specially well adapted for rapid filtration, because, after they have become charged with organic matter, they can be dried and will have lost but little of their original value as fuel.

We shall now describe a few appliances which have been used for the rapid filtration of water. Among filters used in the household, we may mention the Pasteur filter as one of the best. This consists of tubes made of unglazed porcelain, so arranged that the water, introduced into a compartment where these tubes are erected, filters into them, the clear water being drawn out from the bottom. It has been found that this material is, for a considerable time, highly efficient in keeping out all living organisms, but it

should not be forgotten that the tubes need frequent cleaning, as a slimy coat forms on the outside and eventually impairs the effectiveness of the filter. Besides cleaning them periodically, the frequency of the period depending on the character of the water and upon the quantity used, they should occasionally receive a boiling, so that any bacteria that may have entered the material may be destroyed.

Other efficient forms of domestic filters use charcoal or coke as their filtering material. Others have fine sand and some have finely divided iron. The difference in their value depends upon the proper disposition of the materials and upon the facilities for cleaning them. All such house filters very soon lose their efficiency by becoming clogged. To insure a fair degree of healthfulness of the water, it is almost essential to have them cleaned once a day, even though the water still runs clear. This may be necessary merely with regard to the surface layers, the entire filter being cleaned at longer intervals. There are, in the market, filters so arranged that, whenever desired, they can very easily be cleaned, by merely reversing the current of water. This drives out the suspended matter which has been collected, and washes the material. Such filters, while generally more expensive, are vastly superior to those which do not allow of such frequent washing.

As already mentioned, a filter is improved in its action by adding to the water a precipitant. Attachments can be added to most filters, which allow a certain amount of alum, and, perhaps, other precipitants to be mixed with the water, and thus cause a coagulation of the organic matter, which is thereby more easily retained and itself assists in retaining also large quantities of microbes.

Among the larger filters we may mention those furnished by the New York Filter Company and others, and used extensively in our own country. They are built according to various patterns, as the circumstances may require. These filters act in a similar manner to those already mentioned. The filtering material generally consists of fine sand or coke.

The apparatus of Andrew Howatson for softening very hard water, is somewhat extensively used in England and France. The softening is effected by a continuous addition of lime and soda, and the apparatus requires a daily cleansing. Howatson's industrial filters, having crushed silex, charcoal or polarite as filtering materials, are also used.

With respect to all of these rapid filters, we may say that what is gained in rapidity is lost in efficiency. It is true that the character of the water may be greatly improved; in fact, we may remove all the suspended matter, if the pores of the material are fine enough; it is true likewise that we may cause chemical changes which will improve the water, converting some of the objectionable minerals or gases, and some of the organic matter, into unobjectionable compounds; and finally, it is true that we can remove a very high percentage and occasionally all of the microbes which inhabit the impure water. But we cannot place entire confidence in rapid filtration for always turning out pure water.

We have already observed that rapid filters require frequent attention to keep them clean. If this attention be omitted, the water is worse than in its original state. The accumulation of organic matter in the filter and the equally great accumulation of bacteria, may then render the filter a positive danger by having been converted into a disease-breeding mass. This may occur after a few days of service.

We cannot, therefore, too urgently insist upon knowing the composition and construction of filters that we use, and upon giving them the attention which is absolutely necessary to guard us against the danger which can otherwise arise from them. No rapid filter will remain safe for many days without cleaning, and if much water is drawn from them, they must be cleaned almost daily in order that they may continue to furnish pure water.

We now come to the last division of my subject, viz.: that of *slow* filtration, by which we understand a percolation of water through the filtering material without completely filling its pores. This may be called the natural filtration of water, because in nature this same process trans-

forms the more or less polluted rain and surface water into a pure spring or ground water. It accomplishes the purification not only by removing the suspended and dissolved organic matter, which serves as food for bacteria, but also by removing these bacteria themselves, not by a process of straining, as sometimes takes place in rapid filtration, but, we may say, by a process of starvation.

In the earliest attempts at purification by slow filtration, the effort was merely to clarify the liquid; there was no endeavor to remove the dissolved and invisible suspended matter. Later it was found necessary to pay attention to these matters, and particularly to the removal of particles of an organic nature. Pasteur first proved that fermentation was caused not by decomposing organic matter, but by living organisms, and that living organisms were also the cause of many, and perhaps all, zymotic diseases. It was then discovered that filtration removed most of these organisms or bacteria. It is now known that a perfect filter may, under certain conditions, cause a complete destruction of the organic matter in the presence of these bacteria. It is not known in just what manner they effect this destruction, but that they do so in some way is proven by the fact that, when we destroy the bacteria themselves in the impure water, this passes through a filter merely strained and not deprived of its dissolved organic matter. We may destroy the bacteria, for instance, by mixing with the water some poison, such as chloroform. Again, we find that when the temperature is reduced to the freezing point, the water issues in an impure state. It has also been observed that in darkness the purification is not so efficient as in the light. All of this shows that the conditions conducive to organic life are necessary for the complete purification of water.

We must, therefore, provide conditions which will enable the bacteria to do their work as efficiently as possible. After they have done so and have deprived the water of all of their food, they will, of course, perish from starvation.

One of the important conditions for the life of the bacteria is the presence, in the water, of a certain quantity of oxygen, to be used in the conversion of the organic into

mineral compounds. It is, therefore, necessary to replenish the oxygen by aëration until the purification has been completed. This requirement explains the fact that a continuous filter in which the pores are completely filled with water, eventually prevents the bacteria from completing their work. A supply of the air necessary for their action can be furnished only by what is termed "intermittent" filtration.

Many filters have, however, proven effective for a while without this intermittency, this effectiveness being due to the formation, on top of the filter bed, of a film or skin, consisting of the retained organic matter, most of which is, in some cases, in a coagulated state. The bacteria are then kept out by a straining process similar to that which we mentioned as taking place to some extent by the precipitation method of removing organic matter and bacteria. But in time this layer of coagulated matter will obstruct the filter completely, and it requires to be periodically removed. Experience has shown that, immediately after cleaning, a large number of bacteria will pass through into the effluent water. After a while, again a fresh skin forms and the water becomes purer, because there is once more a fine strainer to keep the objectionable particles from passing through. A permanently effective filter, therefore, requires intermittency, by which the bacteria are destroyed through the more or less complete oxidation of the organic matter, caused by a liberal contact with air in the interstices of the material. In certain cases, in which the water naturally contains a sufficient quantity of oxygen, continuous filtration produces excellent results. The carbon is converted into carbonic acid and the nitrogen into nitric acid, which at once combines with the bases contained in the liquid or the soil, and forms harmless nitrates.

English, German and French scientists have made many investigations on this subject, and have reached some valuable conclusions; but it remained for the Massachusetts State Board of Health, through the investigations mainly of Messrs. Mills, Sedgwick, Drown, Hazen and Fuller, to investigate the subject systematically on a large scale and

to formulate its principles in a definite, tangible and practical manner. The results of the Massachusetts investigation have been published in the annual reports of the State Board of Health. They have also been summarized in several papers read before the International Engineering and Public Health Congress in Chicago last summer, by Messrs. Hiram F. Mills and George W. Fuller.*

From these we may quote as follows: "The circumstances that bring most clearly to mind the essential conditions of intermittent filtration are these: A bed of gravel stones, as large as robin's eggs, having an abundance of nitrifying organisms attached to each stone, has sewage poured over it for a short time; after the sewage has settled away, every stone it has reached is covered with a thin film of liquid in contact with air and enveloping the nitrifying organisms. Then nitrification takes place rapidly and with great completeness. A single hour will make a marked change in the character of the adhering liquid.

"After a few hours another charge of sewage distributed over the filter will mingle somewhat with the former adhering liquid and cause it to move downward. If this charge is too abundant, a part of it may flow too rapidly through the large interstices between the stones and reach the outlet drains without being completely nitrified. This condition limits the amount that can be purified by coarse materials. The air spaces are larger than necessary, and the area of surface is small. By decreasing the diameter of the stones to one-tenth of their present diameter, we may still have the same amount of air and water space and ten times the surface to which the water may adhere. In this case the air spaces between the films, though very much smaller than before, are sufficient to supply the oxygen necessary for nitrification if we allow sufficient time between applications for the sand to become drained. It is, however, evident that if we continue diminishing the diameter of the grains

*"Purification of Sewage and of Water by Filtration." By Hiram F. Mills, A.M., C.E.; "Removal of Pathogenic Bacteria by Sand Filtration." By George W. Fuller.; Papers prepared for the International Engineering Congress of the Columbian Exposition. 1893.

of material, we shall reach a condition in which the films of water adhering to the grains will occupy the whole space; there is then no room for air, and nitrification cannot take place. Sand in a filter bed, that remains saturated after draining twenty-four hours, is of little value, and may be very objectionable."

Up to the present time the experiments of the State Board of Health indicate that the sand of even grain, that presents the conditions most favorable for the complete purification of sewage, has a diameter of grain of about 0·2 of a millimeter, or about 0·008 of an inch.

The quantity of sewage that may be permanently, though intermittently, applied to filters of such sand, is about 100,000 gallons per acre daily.

"The very complete purification here referred to produces an effluent chemically as good as many drinking waters, having in 100,000 parts about 0·0020 part of free ammonia, and about 0·0130 part of albuminoid ammonia, the former being but one-tenth of one per cent. and the latter but two per cent. of the amount in the sewage. Nearly all of the organic matter of the sewage is oxidized, forming, in the effluent, soluble nitrates to the extent of about 1·8 parts in 100,000. Bacteriologically, the results are even more remarkable, there remaining in the effluent less than 1 in 10,000 of the number applied in the sewage. The appearance of the effluent is that of a bright, clear spring water."

The surface of the filter should, in the intermissions between the applications, remain uncovered for a period much longer than that during which it is covered.

Polluted water supplies may be purified in a similar manner. As they, however, contain some free oxygen dissolved they do not require so much air in the sand as does sewage. Hence, much larger quantities, say, ten to twenty times as much, or between 1,000,000 and 2,000,000 gallons daily per acre, can be passed through the filter.

In this case, the accumulation of suspended matter is more rapid, and, in order to maintain the efficiency of the filter, the deposits should be removed at more frequent inter-

vals. It was found that 60,000,000 gallons of water, passing through one acre of the sand, as mentioned above, required the removal of one-eighth of an inch of sand and sediment. Therefore, when filtering 2,000,000 gallons daily, about one-eighth of an inch should be removed every thirty days.

"Most of the tests which the State Board of Health relies upon, as giving the efficiency of different filters in removing disease germs, have been made by applying to the filters water containing large numbers of the typhoid bacillus or of the more easily recognized *Bacillus prodigiosus*.

"These tests show that the best sands containing large numbers of these bacilli may have from 1,500,000 to 3,000,000 gallons of water filtered daily per acre, with the constant removal of more than 99½ per cent. of their number.

"In actual practice such results can only be obtained by constructing the filters with great care, so that the sand forms a homogeneous mass without stratification or channels with coarser grains, allowing a larger quantity of water to pass through the interstices. Mr. Mills has recently designed and built a filter at Lawrence, Mass., for the purification of the Merrimac River water which supplies the city, based upon the results obtained by the investigations of the State Board of Health. It is the first filter for water supplies that has been built in this country, where the principle of intermittency has been consistently and intelligently applied, and the results so far have amply rewarded the care taken in the construction, and confirmed the results obtained in the smaller experimental filters of the State Board of Health. It covers an area of two and one-half acres and has a capacity of 5,000,000 gallons daily.

"In summing up our present knowledge of the removal of pathogenic bacteria from drinking water, we may state that in addition to the experience of certain European cities, the Lawrence investigations, covering more than five years and including the bacterial examinations of more than 11,000 samples of water, indicate that it is entirely practicable to construct filters which will purify water economically, and remove more than ninety-nine per cent. of the bacteria in the unfiltered water."

SCIENCE IN THE FOUNDRY.

A Prospective and a Retrospective View.

By Alex. E. Outerbridge, Jr.

In a paper upon progress in applied science, which appeared in February, 1882, in an educational magazine called the *Penn Monthly*, the writer, foreseeing the dawn of a new era in metallurgical science as applied to foundry practice, said: "The chemistry of iron is being more carefully studied. Manufacturers are beginning to realize that pig iron is not a simple substance, but is, in reality, an alloy, composed of a number of dissimilar elements; that its physical characteristics, such as strength, elasticity, etc., depend upon the percentages of these constituents, and that pure iron, like pure gold, is always the same thing physically and chemically, no matter from what source it may be obtained.

"We believe that the time is coming when pig iron will be sold on its chemical analysis, instead of on the crude methods of grading at present in vogue; and further, that, as the naturalist can accurately tell the genus of an animal from an examination of a single bone, so the analyst will tell the physical qualities of a mass of iron from an analysis of its component parts."

Events have proved that this statement was at least partially prophetic.

Not many years ago, a chemist in a foundry, would have been generally regarded as a curiosity, and the idea of controlling foundry mixtures by chemical analysis, would have been considered an expensive refinement.

It is true that, in a few special cases, scientific methods had been tentatively tried years ago, for instance, in the manufacture of chilled cast-iron car wheels, where a product of peculiar quality and uniform character was absolutely requisite, and where also changed conditions of business necessitated new methods.

The "ideal" iron for car wheels is a metal having an extremely dark, "open-grained," or coarse fracture, in the body or "plate" of the wheel, and a pure white, fine-grained adamantine structure, on the "tread," extending to a depth of about half an inch beneath the surface, and merging gradually into the soft gray iron backing.

According to the old nomenclature, such metal may be said to have a gray iron fracture, equivalent to "No. IX," with an artificial crystallization, or chilling quality, equal to "No. 6," or white iron. Formerly, this ideal quality of metal for car-wheels was actually produced in this country, and there is no doubt that this essentially American industry was indebted to that fact for its origin contemporaneously with the birth of the railway system half a century ago.

The gradual dismantling of old-time cold blast charcoal iron furnaces, and the increasing difficulty of obtaining pig iron adapted to the manufacture of chilled wheels, compelled the makers of this product to investigate chemically the elements composing such metal, with the view of ascertaining definitely the cause of the special property of "chilling," which, for many years, was peculiar to pig iron made with charcoal fuel by a cold blast, and could not be successfully produced by any other method of manufacture. The entering wedge in this study was introduced about the year 1879, by Dr. Dudley, chemist to the Pennsylvania Railroad; and, shortly after this, the writer was called upon to take up a similar work for a large establishment in Philadelphia, engaged since 1847, in the manufacture of chilled wheels.

Dr. Dudley generously imparted the facts which he had gathered in the midst of many other important lines of investigation, and the writer took up these threads and found interesting occupation, extending over a period of several years, in weaving them together.

Some of the practical results of this investigation were embodied in a paper entitled the "Genesis of a Car Wheel," read before the Chemical Section of the Franklin Institute, in 1883, and later, in the more popular form of a lecture at

the same institution in 1888, on "Pig Iron: Including the Relation between its Physical Properties and its Chemical Constituents."*

It is admitted that chemical investigation has not only saved the car wheel industry from extinction, but also that it has enabled the manufacturer to turn out product to-day, which is subject to far more severe scrutiny before passing into service, and to vastly greater shocks and strains in ordinary use than heretofore, and at a minimum price. Indeed, it may be said in passing, that not the least wonderful feature of this special business is the price at which chilled cast-iron car wheels of good quality are now sold.

Within a very few years the subject of "Chemistry in the Foundry" has run riot in the discussions of the foundrymen's associations and in the journals devoted to iron interests. A vast amount of "green fruit" has been put upon the market, much of which has already withered before ripening; but this is not an unusual experience, and in taking a broad view of the subject, one can observe that considerable progress has been made.

Scientific system is gradually superseding rule-of-thumb, or empirical, methods, in progressive foundries, and much of the old-time superstition, born of ignorance, is being eradicated. This is true, not only in regard to the metallurgy of pig iron for castings, but also in regard to methods of moulding and other cognate branches of the founder's art. The influence of this newly-awakened interest is extending with results that are apparent in widely divergent directions. Pig iron is no longer valued solely by its appearance when fractured, but by its chemical constitution. The manufacturer of machinery is enabled to obtain castings from such foundries which are more certainly adapted to the special work for which they are designed, and he is also enabled to guarantee their quality, in regard to strength, etc.

The technical colleges are being equipped with improved testing machines of large capacity and marvellous accuracy,

* *Vide*, this *Journal*, [125,] 223.

and the number of students devoting themselves to the metallurgy and chemistry of pig iron is increasing.

From these observations it may be inferred that, although the field for cast iron has been invaded to a great extent by cast steel, the producers of iron castings have been spurred on to improve their product, and thus to keep in line with the progress of the age, and to show that in spite of this formidable competition the field is still open for their occupation.

NOTES AND COMMENTS.*

THE SHIP CANAL THROUGH THE LAKES.

The daily journals contain the announcement that a bill has been introduced in the Senate authorizing the President to appoint three persons to confer with any similar committee appointed by Great Britain or Canada, and to report as to the feasibility of a canal for ocean vessels between the Atlantic and the Lakes; where it can most conveniently be located; the probable cost, with estimates in detail; and, if any part of the canal should be built in Canada, what arrangements are necessary to preserve it for use to the people of this country. All the necessary facts relating to the construction and use of such deep-water channel are also to be reported on, and it is proposed to appropriate $10,000, or so much thereof as may be necessary, for actual travelling and other necessary expenses, the members of the commission to serve without pay.

In view of the fact referred to in my annual report to the Institute, that the Dominion of Canada has already expended the enormous sum of $67,000,000 for the construction, on Canadian territory, of a continuous chain of waterways connecting the Great Lakes with the Ocean, and navigable by ocean-going vessels, it is exceedingly improbable that either Canada or the mother country would wish to confer upon a matter that is already practically *un fait accompli;* and especially since the manifest purpose of this Canadian enterprise, as I had occasion to point out in my previous communication, is to render the Dominion independent of the United States in the possession of this important avenue to the Ocean.

PRESENT CONDITION OF NIAGARA FALLS POWER PLANT.

Prof. George Forbes, in a recent communication to the London *Times*, describes the present condition of the power plant at Niagara Falls as follows: "Nearly three years ago you published a letter from this place in which I gave some account of how the dreams of the engineer were in the act of being realized, and without injury to the natural beauties of the spot. Three years have passed, my work is ended, and it seems natural to continue

* From the report of the Secretary to the stated meeting of the Institute, held February 20, 1895.

the narrative and tell what these three years have brought forth. I am perched on top of a small Eiffel tower, lately erected, and, casting my eyes up the river, over the housetops and beyond the town, I see a new world created. There is a wide canal leading water into that gigantic power house, where three turbines are set up to drive three dynamos of 5,000 horse-power each. There is the bridge to carry cables across to the transformer house. Inside the power house the water is carried down by pipes 7½ feet diameter into the turbines, whence it passes through a 7,000 feet tunnel under the town, emerging below the Falls, and capable of developing 100,000 horse-power. Far as the eye can reach extend the company's lands, with here and there a huge factory either now using the water-power, or waiting for the electric supply. One of them uses 3,300 horse-power, another 300, a third one 1,500, and that unfinished mill requires 1,000. You can see, far away, the model village for workingmen and improved sewage works with drainage, pumps for water supply, electric light and well-paved streets. There, again, is the dock, where ships from all parts of the Great Lakes can unload, and there a huge expanse of reclaimed land; while the whole is swept by the company's railway, seven miles long, connecting every factory with the great trunk lines. The power is transmitted by electricity, and the first work is to produce aluminum with 1,500 horse-power. New types of machines have been devised for this work, as also for every other purpose. All criticism as to cost of electric works has been swept away by the results achieved, and the efficiency of each type of machine is greater than has been attained before. All the machinery for the first working has been made and tested in the shops, and the last parts are now being set up. The plans for carrying the power to Buffalo, eighteen miles distant, are complete. In a month or two factories will be in full operation; in a year Buffalo will be supplied; in two years the same company will be working the Canadian side of the Falls, and in ten years (shall we say?) the whole of the 100,000 horse-power which can be supplied by the existing hydraulic works will be giving power to smokeless manufacturing towns. The period of planning the transmission scheme, of designing the greatest dynamos in the world, and of construction of the first plant now closes. The financial period commences with the new year. The earning of dividends and the ordering of duplicate machinery is the future work of the company. In conclusion, it is difficult for me to say who were the boldest—the capitalists who embarked on the scheme before any plans were matured, or the manufacturers who moved their factories to this field before a single result had been achieved. The action of both was typically American, but their confidence was not misplaced. Their success is now assured."

I take from the *Electrical Engineer* the following account of the condition of the electrical part of the plant:

The turbines built by the I. P. Morris Company are in position and all the galleries, the ladders, the elevators and the electric lights have been placed in the wheel pit.

Men are now at work putting in the turbine oiling apparatus, with the tanks, filters, pipes and pumps. A novel way of operating the force pumps

which take the oil up through the pipes to the upper tank has been developed. All the water which leaks into the wheel pit is collected by a ring around the pit into a reservoir about a third of the way down the pit, and is used to run the pumps. A pressure of ninety pounds to the inch is secured by this surplus water.

The main-switch-board room in the power house is also well under way. It is to be constructed of white enamelled brick, and when finished will be 58 feet long, 13 feet wide and 8 feet high. The front will be composed of ten heavy plate-glass windows, while the top of the inclosure will be an observation platform, inclosed in a brass railing, for visitors. This room will contain some of the heaviest switches thus far constructed, and will be one of the most interesting features of the power plant. The transformer building, which stands over the mouth of the electric subway, is also well up to the roof. It is of the same style of architecture as the main power building, massively constructed.

The alternating current dynamos, built by the Westinghouse Company, are thus described:

To a circular foundation is bolted a vertical cast-iron cylinder, provided with a flange on which the stationary armature rests. The inner part of the cylinder is bored to the shape of an inverted cone, and serves as a bearing for another conical piece of cast iron supporting the shaft bearings. The armature core is made of thin oxidized iron plates, held together by eight nickel steel bolts. In the outer edge of the plates are 187 rectangular holes to receive the armature winding.

The outer rotating field magnet consists of a wrought-steel ring, to which are bolted the twelve inwardly-projecting massive cast-iron pole pieces. The ring constituting the field magnet is supported by a six-armed cast-steel spider keyed to a vertical axis. The field magnets act also as a fly-wheel. The shaft rests on two bearings supported by four arms projecting from the inner adjustable cast-iron cylinder. The bushings of the bearings are made of bronze provided with zig-zag grooves, in which oil constantly circulates. On the outer side of the bushing there are also grooves into which cold water may be pumped if required.

The armature conductors are rectangular copper bars 32 x 8 mm. and each of the 187 holes of the armature contains two of these bars, surrounded with mica. The upper and under sides of the armature are connected by means of V-shaped copper bars, riveted to the ends of the bars, which project out behind the ends of the armature. The connections are made so as to give two independent circuits, a pair of cables connecting each circuit with the switch-board. The magnet winding is also composed of bent copper bars, air insulated, inclosed in brass boxes, two of which are fastened to each pole piece. Continuous current for exciting the field magnets is obtained from a rotary transformer.

The current is conducted to the field coils by means of a pair of brushes and two copper rings fixed to the top of the shaft of the generator. At a speed of 250 revolutions per minute the machine produces two alternating currents, differing in phase 90° from each other, each of 775 ampères and

2,250 volts pressure. The alternations are fifty per second. The height from base of bed plate to top of machine is nearly 13½ feet.

A SUBSTITUTE WANTED FOR WOOD IN THE CONSTRUCTION OF WARSHIPS.

A board of experts, of which Commissioner Bradford is senior member, was lately convened by direction of the Secretary of the Navy to consider the subject of dispensing with wood in the construction of the naval ships now building, and also for the purpose of finding some suitable substitute for wood in places where it is impracticable to use metal. Since the naval action fought off the mouth of the Yalu River, between the Chinese and Japanese fleets, during which several ships were disabled and thrown out of action by serious fires on board, the matter has received much attention at home and abroad. The German Admiralty has convened a board to find a suitable substitute for wood; in the meantime, the use of wood on other ships has ceased altogether, even the furniture being made of iron, and cork being used where a non-conductor is absolutely necessary.

The English, it is stated, have not yet come to any decision in the premises, but are casting about for some substitute for wood. The French have for a long time used a minimum of wood, and, in all foreign ships, less wood has probably been used than in those of our service.

The problem is not an easy one. While there is no doubt that the abolition of all combustible material will add to the fighting efficiency of ships of war, there would be serious risk that they would be rendered uninhabitable. Owing to the good conducting properties of iron and steel the living quarters, if not sheathed with some non-conductor, become intensely cold in winter and very hot in summer. Where heat is applied, owing to the difference of temperature on the opposite sides of the metal plating, much condensation of moisture occurs. These conditions are active agencies in the causation of rheumatism and pulmonary diseases. Clothing kept in metal drawers and lockers becomes ruined from moisture, and the drawers must be lined with something in the nature of wood or thick felt. The board has decided that a substitute for wood should have the following properties:

It should be light, or no heavier than wood, non-conducting, non-combustible, and, when struck by shot, should not fly into splinters. When used for bulkheads, berths, shelves, lockers, etc., it should be strong and capable of being worked into shapes with tools. For linings on metal, no great strength is required. Several manufacturers of metal goods and furniture have offered to make samples for the board to pass upon. Chemists and others are engaged in experiments with the object of producing an artificial wood. Manufacturers of fire-proof paints and liquids have given some very successful exhibitions of their wares; but surface protection of wood, however, is insufficient and of no avail when the wood becomes splintered by a hailstorm of small projectiles. Furthermore, wood has the very objectionable property of splintering from the effect of shot and the fact is well known

that, in wooden ships, frequently, as many persons are wounded by splinters as by shot.

A solution of the problem of finding a substitute for wood, seems, in the opinion of the board, to lie in the following direction:

Take something in the nature of cheap wood or vegetable fibre and fine sawdust; treat them chemically with some insoluble fire-proof substance, not too heavy; then press and roll into boards, more or less dense, according to the use for which the material is desired. Such a material will be non-inflammable all through, will not splinter, will not be heavy and will be a non-conductor. Possibly this artificial board can be strengthened by enclosing within it a tough, fine, wire netting. If sawdust, or other fine cellulose material, after being rendered non-inflammable, can, by mixing with other materials not too heavy—or, if heavy, in small quantities—be applied to metal in a plastic state, so as to harden into a compact mass impervious to water, then it will be of great value. In other words, if a light, non-conducting, non-inflammable, insoluble cement can be discovered, it will be of great use in ship construction.

THE COMMERCIAL SYNTHESIS OF ILLUMINATING HYDROCARBONS.

In the report which I had the honor to present at the December meeting of the Institute, I made reference to the interesting announcement by Mr. T. L. Willson, of a cheap and practical method of producing calcium carbide, by heating an intimate mixture of lime and carbon in the electric furnace, and explained the method of producing acetylene from this compound by bringing it in contact with water. An abstract was published in the *Journal* for January, 1895, of a paper by Dr. Francis Wyatt, giving details of the method of manufacture, and indicating in a general way the probable future utility of this observation.

The following additional contribution to the subject, which is abstracted from a paper lately read before the London *Society of Arts*, by Prof. Vivian B. Lewes, throws considerable light upon it, and will be read with interest:

"The direct combination of carbon and hydrogen in the electric arc is a true case of synthesis, and if we could form acetylene in this way in sufficiently large quantities, it would be perfectly easy to build up from the acetylene the whole of the other hydrocarbons which can be used for illuminating purposes. For instance, if acetylene be passed through a tube heated to just visible redness, it is rapidly and readily converted into benzol; at a higher temperature, naphthalene is produced; whilst, by the action of nascent hydrogen on acetylene, ethylene and ethane can be built up. From the benzol we readily derive aniline, and the whole of that magnificent series of coloring matters which have gladdened the heart of the fair portion of the community during the past five-and-twenty years; whilst the ethylene produced from acetylene, can readily be converted into ethyl alcohol, by consecutively treating it with sulphuric acid and water. From the alcohol,

again, an enormous number of other organic substances can be produced, so that acetylene can, without exaggeration, be looked upon as one of the great keystones of the organic edifice, and, given a cheap and easy method of preparing this substance, it is hardly possible to foresee the results which will be ultimately produced.

"In 1836, it was found that when making potassium, by distillation from potassic carbonate and carbon, small quantities of a by-product, consisting of a compound of potassium and carbon, was produced, and that this was decomposed by water with liberation of acetylene; whilst Wöhler, by fusing an alloy of zinc and calcium with carbon, made calcic carbide, and used it as a source from which to obtain acetylene by the action of water.

"Nothing more was done until 1892, when Macquenne prepared barium carbide, by heating, at a high temperature, a mixture of barium carbonate, powdered magnesium, and charcoal, the resulting mass evolving acetylene, when treated with water; whilst, still later, Travers made calcic carbide, by heating together calcic chloride, carbon and sodium. None of these processes, however, gave any commercial promise, as the costly nature of the potassium, sodium, magnesium, or calcium-zinc alloy which had to be used, made the acetylene produced from the carbide too expensive.

"Whilst working with an electric furnace, and endeavoring by its aid to form an alloy of calcium from some of its compounds, Mr. T. L. Willson noticed that a mixture, containing lime and powdered anthracite, under the influence of the temperature of the arc, fused down to a heavy semi-metallic mass, which having been examined, and found not to be the substance sought, was thrown into a bucket containing water, with the result that violent effervescence of the water marked the rapid evolution of a gas, the overwhelming odor of which enforced attention to its presence, and which, on the application of a light, burnt with a smoky, but luminous flame.

"Investigation into the cause of this phenomenon soon showed that in a properly constructed electric furnace, finely powdered chalk or lime, mixed with powdered carbon in any form, whether it were charcoal, anthracite, coke, coal or graphite, can be fused with the formation of a compound known as calcic carbide, containing 40 parts by weight of the element calcium, the basis of lime, and 24 parts by weight of carbon, and that, on the addition to this of water, a double decomposition takes place, the oxygen of the water combining with the calcium of the calcic carbide to form calcic oxide or lime, whilst the hydrogen unites with the carbon of the calcic carbide to form acetylene, the cost of the gas so produced bringing it not only within the range of commercial possibilities for use *per se*, but also the building up from it of a host of other compounds, whilst the production of the calcic carbide from chalk and from any form of carbon, renders us practically independent of coal and oil, and places in our hands the prime factor by which nature in all probability produces those great underground storehouses of liquid fuel upon which the world is so largely drawing to-day.

"Calcic carbide is a dark gray substance, having a specific gravity of 2·262, and, when pure, a pound of it will yield on decomposition 5·3 cubic feet of acetylene. Unless, however, it is quite fresh, or means have been taken to

carefully protect it from air, the outer surface gets slightly acted upon by atmospheric moisture, so that in practice the yield would not exceed 5 cubic feet. The density and hardness of the mass, however, to a great extent protect it from atmospheric action, so that in lumps it does not deteriorate as fast as would be expected, but in the powdered condition it is rapidly acted upon.

"The acetylene made from it, when analyzed by absorption with bromine, the analysis being also checked by determining the amount present by precipitation of silver acetylide, gives 98 per cent. of acetylene and 2 per cent. of air, and traces of sulphuretted hydrogen; the presence of this impurity being due to traces of sulphate of lime—gypsum—in the chalk used for making it, and to pyrites in the coal employed.

"Acetylene is a clear, colorless gas with an intensely penetrating odor which somewhat resembles garlic, its strong smell being a very great safeguard in its use, as the smallest leakage would be at once detected; indeed, so pungent is this odor, that it would be impossible, without recognizing the fact, to go into a room which contained any dangerous quantity of the gas.

"This is an important point to remember, as the researches of Bistrow and Liebreich show that the gas is poisonous, combining with the hæmoglobin of the blood to form a compound similar to that produced by carbon monoxide; whilst the great danger of the latter gas is, that, having no smell, its presence is not detected until symptoms of poisoning begin to show themselves. With acetylene no fear need be apprehended of danger from this cause.

"Acetylene is soluble in water and in most other liquids, and, at ordinary temperature and pressure—60° F. and 30″ of mercury—10 volumes of water will absorb 11 volumes of the gas; but, as soon as the gas is dissolved, the water being saturated takes up no more. Water already saturated with coal gas does not take up acetylene quite so readily, whilst the gas is practically insoluble in saturated brine—100 volumes of a saturated salt solution dissolving only 5 volumes of the gas. The gas is far more soluble in alcohol, which, at normal temperature and pressure, takes up six times its own volume of the acetylene; whilst 10 volumes of paraffin, under the same conditions, will absorb 26 volumes of the gas. It is a heavy gas, having a specific gravity of 0·91.

"When a light is applied to acetylene, it burns with a luminous and intensely smoky flame, and, when a mixture of one volume of acetylene with one volume of air is ignited, in a cylinder, a dull red flame runs down the cylinder, leaving behind a mass of soot, and throwing out a dense black smoke. When acetylene is mixed with 1·25 times its own volume of air, the mixture begins to be slightly explosive, the explosive violence increasing until it reaches a maximum with about twelve times its volume of air, and gradually decreasing in violence, until, with a mixture of one volume of acetylene to twenty of air, it ceases to be explosive.

"The gas can be condensed to a liquid by pressure. Andsell found that it liquefied at a pressure of 21·5 atmospheres, at a temperature of 0° C.; whilst Cailletet found that, at 1° C., it required a pressure of 48 atmospheres; the first-named pressure being probably about the correct one. The liquid

so produced is mobile, and highly refractive, and, when sprayed into air, the conversion of the liquid into the gaseous condition absorbs so much heat that some of the escaping liquid is converted into a snow-like solid, which catches fire on applying a light to it, and burns until the solid is all converted into gas and is consumed.

"In my researches upon the luminosity of flame, I have shown that all the hydrocarbons present in coal gas and other luminous flames, are converted, by the baking action taking place in the inner non-luminous zone of the flame, into acetylene, before any luminosity is produced, and that it is the acetylene, which, by its rapid decomposition at 1,200° C., provides the luminous flame with these carbon particles, which, being heated to incandescence by various causes, endow the flame with the power of emitting light. The acetylene, being in this way proved to be the cause of luminosity, one would expect that in this gas we have the most powerful of the gaseous hydrocarbon illuminants, and experiment at once shows that this is the case.

"Owing to its intense richness, it can only be consumed in small flat-flame burners, but under these conditions emits a light greater than that given by any other known gas, its illuminating value calculated to a consumption of 5 cubic feet an hour being no less than 240 candles.

ILLUMINATING POWER OF HYDROCARBONS FOR A CONSUMPTION OF 5 CUBIC FEET OF GAS.

	Candles.
Methane	5·2
Ethane	35·7
Propane	56·7
Ethylene	70·0
Butylene	123·0
Acetylene	240·0

"It is stated that the carbide can be made at about £4 a ton; and if this be so, it should have a great future, as a ton will yield 11,000 cubic feet of the gas. The lime left as a by-product would be worth 10*s.* a ton, and the gas would cost at this rate 6*s.* 4½*d.* per 1,000 cubic feet, and, in illuminating value, would be equal to London coal gas at 6*d.* a thousand. Its easy production would make it available for illuminating purposes in country houses, whilst its high illuminating value should make it useful for enriching poor coal gas."

A NEW ELEMENT IN THE NITROGEN GROUP.

Mr. A. E. Tuttle communicates to London *Nature*, the following concise abstract of an important communication made by Dr. Beyer to the *Société Chimique*, describing a new element which he has discovered in the residual liquors derived from the older process for the extraction of aluminum from red beauxite. The liquors in question consist chiefly of sulphate and carbonate of sodium; but there are also present considerable quantities of chromic and vanadic acids; and smaller quantities of molybdic, silicic, arsenic, phosphoric, and tungstic acids; together with alumina, magnesia and lime, and an acid of the new element. In order to isolate the latter, the vanadium and chromium are first removed, the former as the difficultly-soluble ammonium van-

adate, and the latter as hydrated sesquioxide. The filtered liquid is then saturated with sulphuretted hydrogen, and the sulphides, all of which are soluble in the alkaline liquid, are precipitated by hydrochloric acid. This precipitate exhibits a deep brown color, due to the new element. When dried, it presents a brown, earthy appearance, and burns readily with evolution of sulphur dioxide and formation of a bright brown powder. Concentrated nitric acid instantly causes ignition, and formation of a deep brown solution, from which a small quantity of a yellow precipitate of a compound of molybdic and arsenic acids is deposited. The brown liquid contains no tin, antimony or tellurium, but still retains traces of vanadium, molybdenum and selenium These elements are best removed by calcination of the sulphides immediately after their precipitation with hydrochloric acid; when selenium is volatilized, treatment of the residue with ammonia and ammonium nitrate, which precipitate the last traces of vanadium as ammonium vanadate; and concentration of the filtered liquid, which causes deposition of ammonium molybdate. During the concentration two distinct crops of different crystals are obtained, the first, and most sparingly soluble, being cubic crystals of an olive-brown color; and the second, the much more soluble ammonium molybdate. The olive-brown cubic crystals contain the new element, together with a little molybdenum. The latter is readily removed by dissolving the crystals in dilute hydrochloric acid, and passing a current of sulphuretted hydrogen through the liquid heated to about 70°. The new element is not precipitated by sulphuretted hydrogen, in an acid solution. The filtered liquid is then allowed to evaporate in the air. At first it is bluish-violet in color, and contains the new element in a low state of oxidation; subsequently it becomes oxidized, and the color changes to lemon-yellow. The oxide in the latter stage possesses marked acid proclivities, and probably corresponds to the formula R_2O_5. The acid itself is soluble in water, from which it is deposited in yellow crystals, which, at a red heat, fuse to a brownish yellow mass. Ammonia transforms the acid into a crystalline powder of olive color, presumably an ammonium salt, which readily dissolves in hot water and on cooling crystallizes from the solution in cubes. The solution is olive-green, and is precipitated by strong ammonia. The solution of the acid, after reduction with sulphuretted hydrogen in presence of hydrochloric acid, yields with ammonia, a voluminous deep violet-brown precipitate, which rapidly becomes crystalline. The precipitation is not complete, hence the supernatant liquid is colored violet. Caustic soda and sodium carbonate, likewise, incompletely precipitate it, owing to solubility of the precipitate in excess of the reagent with formation of a soluble salt. Chlorides of barium and calcium produce grayish-violet precipitates of the salts of those metals.

An especially interesting reaction is that with ammonium sulphide, with which, the highly oxidized yellow solution of the acid, yields a deep cherry-red coloration, due to a sulpho-salt. Acids precipitate from this solution a sulphide of the color of iron rust. Silver nitrate produces a green precipitate of the silver salt, soluble both in nitric acid and in ammonia, and if the solution in the latter solvent is effected at a moderately elevated temperature the, silver salt is deposited in crystals upon cooling. Magnesia mixture gives,

after standing a few minutes, a green precipitate analogous to ammonium-magnesium phosphate, and, owing to the slowness of the precipitation, the latter occurs in the form of relatively large crystals; moreover, the precipitation is complete after a short time, for the liquid, which at first is green, becomes colorless. A yellow precipitate is likewise afforded with a nitric acid solution of ammonium molybdate, as in the case of phosphoric acid. The chlorides of the new element appear to be volatile, for very considerable loss occurs on attempting to remove by ignition any admixed ammonium salts, for instance, from the solution obtained after removal of the vanadium as previously described. A yellow sublimate is produced having all the characters of a chloride of the new element, and which is readily soluble in water.

A sufficient quantity of the new element, in the form of any of its compounds, has not yet been accumulated to enable exact quantitative analyses to be carried out, but Dr. Bayer hopes shortly to have obtained the amount requisite for this purpose and for the determination of the atomic weight of the element. There appears to be little room for doubt that it will prove to be one of the missing elements predicted by Professor Mendeléeff in the nitrogen-phosphorus group. It exhibits characteristic spectroscopic lines in the green, blue and violet.

ARGON: A NEW CONSTITUENT OF THE ATMOSPHERE.

In a paper bearing this title, recently read before the Royal Society, Lord Rayleigh and Professor Ramsay described the results of their researches into the nature and properties of argon, the new constituent of the atmosphere.

The following abstract of this communication is taken from the *Engineering and Mining Journal:*

The separation of the unknown constituent was effected, as stated at the meeting of the British Association, by two different methods—absorption of nitrogen by red-hot magnesium, and a repetition of the experiment in which Cavendish removed the nitrogen by electric sparking in the presence of excess of oxygen and an alkali. An estimate was founded upon the data respecting the volume present in air, on the assumption that the densities of atmospheric and chemical nitrogen differ only on account of the presence of argon in the former, and that nothing but nitrogen is oxidized during the treatment with oxygen. According to this mode of calculation the density is 20·6. Calculation from the weight of a mixture of argon with oxygen gives, however, a density of 19·7. The most trustworthy results of a number of determinations of the density of argon prepared by means of magnesium, give the figure 19·9, which is the one practically accepted by the authors. By considerations drawn from the ratio of specific heats, the authors are led to regard argon as a monatomic gas, like mercury, and its atomic weight is therefore not twenty, but forty. Many attempts have been made to induce it to combine, but they have all as yet proved abortive. Argon does not combine with oxygen, in presence of alkali, under the influence of the electric discharge; nor with hydrogen, in presence of acid or alkali, when sparked; nor

with chlorine, dry or moist, when sparked; nor with phosphorus at a bright red heat; nor with sulphur at bright redness. Tellurium may be distilled in a current of the gas; so may sodium and potassium, their metallic lustre remaining unchanged. It is not absorbed when passed over fused red-hot caustic soda, or soda-lime heated to bright redness; it passes unaffected over fused and bright red-hot potassium nitrate, and red-hot sodium peroxide does not combine with it. Persulphides of sodium and calcium are also without action at a red heat. Platinum black does not absorb it, nor does platinum sponge, and wet ozidizing and chlorinating agents, such as nitro-hydrochloric acid, bromine water, bromine and alkali, and hydrochloric acid and potassium permanganate, are entirely without action. Experiments with fluorine are in contemplation, but the difficulty is great. An attempt will be made to produce a carbon arc in argon. Mixtures of sodium and silica, and of sodium and boracic anhydride, are also without action; hence it appears to resist attack by nascent silicon and by nascent boron. As to its physical properties, we have a little more information. Its solubility in water is relatively high, being two and a half times that of nitrogen. Its spectroscopic examination has been conducted by Mr. Crookes, who contributed a supplementary paper dealing with that portion of the subject. It has two distinct spectra, as has nitrogen itself. But while the nitrogen spectra are of different characters, one being a line and the other a band spectrum, the two spectra of argon are of the same type. The red lines are described as specially characteristic; there is a bright, yellow line, a group of five in the green, and five strong violet lines, of which the fourth is the most brilliant, and has a wave length of 420. The spectrum is identical, whether the substance be separated by magnesium, or by sparking. According to Professor Olzewski, of Cracow, the critical point of the new gas is 121°; the critical pressure, 50·6 atmospheres; the boiling point-187°; the melting point-189·6°; and the density of the liquid, 1·5.

BOOK NOTICES.

Popular Lectures and Addresses.—By Sir William Thomson (Baron Kelvin). Vol. II. Geology and General Physics. 8vo. Pp. 599. London and New York: Macmillan & Co. 1894.

The present volume of Lord Kelvin's popular lectures and addresses completes the series of three volumes. The theories discussed are well defined in the title of the volume, and several of them have given rise to animated discussion. The distinguished author, who is acknowledged as the leader of thought in the domain of physical science, has advanced views regarding "geological time" and "geological dynamics," which happen to differ substantially from those entertained by the geologists, and which, consequently, have been sharply criticised. The subjects considered in these lectures and addresses are treated in a style fully adapted to the comprehension of the intelligent reader, and, it need scarcely be added, will amply repay careful reading and study. W.

Electrical Papers.—By Oliver Heaviside (2 vols). Cloth. 8vo. Pp. 560-587. New York and London: Macmillan & Co. 1894. Price, $7.

These volumes constitute the collected papers of Mr. Heaviside, who is well known to many readers of the *Journal* for his valuable work as an elucidator of the modern theory of electro-magnetism.

The present edition of the author's works embraces, in addition to his various contributions to this subject, many papers on miscellaneous topics published during the past twenty years. The treatment is mathematical. W.

Electric Waves; being researches on the propagation of electric action with finite velocity through space. By Dr. Hemrich Hertz. London and New York: Macmillan & Co. Pp. xv + 278. Price, $2.50.

The importance to science of this comprehensive review of the theory of electric action cannot be too highly esteemed. It includes within its fourteen chapters, originally contributed to *Wiedemann's Annalen*, and now gathered by Prof. D. E. Jones, B.Sc., into a single volume, the record of scientific discovery, from the time of Newton and Bernoulli down to and including the work of the author himself, which is acknowledged by his contemporaries to be epoch-making. W.

Electricity One Hundred Years Ago and To-Day. With copious notes and extracts. By Edwin J. Houston, Ph.D. (Princeton). New York: The W. J. Johnston Company, Limited, 253 Broadway. Pp. 199. Illustrated. Price, $1.

In tracing the history of electrical science from its infancy to the present day, the author of this work has, wherever possible, consulted original sources of information, and he was fortunate to have at his disposal for this purpose the excellent library of the Franklin Institute, which contains, perhaps, the most complete collection of scientific publications of the last century to be found in this country.

As a result of these researches, several revisions of the dates of discovery of important principles in electrical science were found to be necessary. For example, it was found that Sir Humphrey Davy was anticipated in the discovery of the electric arc by many others, and, in fact, did not claim to have been the first to discover the brilliant effects of the arc. Proper credit is given to Gilbert for his inductive methods, and, in an appendix, several writers are quoted to show that Bacon has been honored above his merit in this respect.

While, as the author states, the compass of the book does not permit of any other than a general treatment of the subject, yet numerous references are given in foot-notes, which, also, in many cases, quote the words in which a discovery was first announced to the world, or give more specific information in regard to the subjects mentioned in the main portion of the book. This feature will be found of interest and value, for often a clearer idea may be obtained from the words of a discoverer of a phenomena or principle than is possible when they are presented at second-hand.

The work is not a mere catalogue of subjects and dates, nor is it couched in

technical language that is intelligible only to a few. On the contrary, one of its most admirable features is the agreeable style in which the work is written, its philosophical discussion as to the cause and effect of various discoveries, and its personal references to great names in electrical science. Much information as to electrical phenomena may also be obtained from the book, as the author is not satisfied to merely give the history of a discovery, but also adds a concise and clear explanation of its nature and scope. W.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, February 20, 1895.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 20, 1895.

Mr. JOS. M. WILSON, President, in the chair.

Present, thirty-nine members and ten visitors.

Additions to membership since last report, seven.

Mr. Henry R. Heyl was elected to fill the vacancy in the office of Vice-President, and Mr. Charles A. Hexamer to fill the vacancy in the Committee on Science and the Arts.

The amendments relating to the organization and government of the Sections, proposed by the Committee on Sectional Arrangements and recommended for adoption by the Board of Managers, were adopted by unanimous vote.

The Secretary presented and read a communication from the *Verein Deutscher Ingenieure*, of Berlin, setting forth the advantages to be attained by the adoption of a uniform system of screw-threads by all civilized nations, and asking whether the Franklin Institute would be disposed to co-operate in an international movement looking to the unification of screw-thread standards.

The meeting voted to authorize the President to appoint a committee to consider the expediency of such co-operation on the part of the Franklin Institute, and to report at the next stated meeting.

Mr. B. P. Wiltberger read a paper entitled "The Application of Cellulose to Men-of-War and to the Merchant Marine." (To be published.)

Mr. Geo. W. Walker, of New York, exhibited and described an improvement in electric lamps of the "incandescent-arc" type, which is manufactured by the Manhattan General Construction Company, of New York. (The subject is under investigation by the Committee on Science and the Arts.)

The Secretary's report (see Notes and Comments) was presented.

Adjourned.

WM. H. WAHL, *Secretary*.

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. TOWNSEND, WEATHER BUREAU, OBSERVER IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR JANUARY, 1895.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 31, 1895.

GENERAL REVIEW.

The average temperature for January, 1895, 24°·2, is 4°·4 below the average [28°·6] for the past seven years.

Most of the highest recorded temperatures occurred on the 7th, 11th and 21st, and were as follows: Pittsburgh, 58°; Uniontown, 58°; Lancaster, 57°; Erie, 55°; Philadelphia, 55°, and Immel Reservoir, 55°.

The lowest were on the 1st, 5th, 13th, 14th, 27th, 28th and 31st: Emporium, minus 17°; Smethport, minus 16°; Wellsboro, minus 16°; Shingle House, minus 15°; Lewisburg, minus 15°, and Dyberry, minus 15°.

From January 1, 1895, to January 31, 1895, the accumulated deficiency in daily mean temperature at Philadelphia was 48°; at Erie, 70°, and at Pittsburgh, 83°.

For the same period the excess in precipitation, in inches, at Philadelphia, was 1·15; Pittsburgh, 0·93, and a deficiency at Erie of 0·01.

TEMPERATURE.

	Mean Temperature.	*Mean Precipitation, Inches.*
January, 1888, ...	22°·1	4·19
1889, ...	31°·9	3·54
1890, ...	37°·7	3·04
1891, ...	30°·6	3·64
1892, ...	26°·3	4·77
1893, ...	19°·3	2·85
1894, ...	32°·7	2·29
1895, ...	24°·2	4·17

The means of the daily maximum and minimum temperatures, 32°·8 and 15°·5, respectively, give a monthly mean of 24°·2, which is 8°·5 below the corresponding month of 1894.

The average daily range was 17°·3.

Highest monthly mean, 30°·8 at *Philadelphia* [Centennial Avenue].

Lowest monthly mean, 16°·8 at Shingle House.

Highest temperature recorded during the month, 58° on the 21st at Pittsburgh and Uniontown.

Lowest temperature, minus 17° on the 31st at Emporium.

Greatest local monthly range, 65° at Cassandria and Uniontown.

Least local monthly range, 41° at Coopersburg.

Greatest daily range, 51° at Saegerstown.

PRECIPITATION.

The average precipitation for the State, for the month, 4·17 inches, is 0·70 inches more than the average [3·47] for the last seven years.

General precipitation (mostly snow) occurred on the 6th, 7th, 8th, 9th, 10th, 11th, 13th, 16th, 21st, 22d, 26th and 29th.

The average snowfall during the month was 14·2 inches, and 10·7 inches remained on the ground at the end of the month.

The largest totals of snowfall in inches were: Somerset, 32; Lock Haven, 29; Grampian, 28; Cassandria, 27; Emporium, 26, and Wellsboro, 25.

The largest monthly totals of rainfall and melted snow in inches were: Somerset, 6·36; Smethport, 5·90; Hamburg, 5·82; Hollidaysburg, 5·74; Pottstown, 5·65, and Phœnixville, 5·47.

The least were: Shingle House, 1·83; Towanda, 1·95; South Eaton, 2·35; Dyberry, 2·95; Confluence, 2·98, and Chambersburg, 3·00.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 13; clear days, 7; fair days, 10; cloudy days, 14.

BAROMETER.

The mean pressure for the month, 30·06, is about ·04 below the normal. At the United States Weather Bureau Stations, the highest observed was 30·54 at Erie on the 8th, and the lowest 29·24 at Erie on the 26th.

MISCELLANEOUS PHENOMENA.

Thunderstorms.—Hollidaysburg, 5th; Johnstown, 6th; Mauch Chunk, 26th; Uniontown, 6th; Lebanon, 5th, 26th; South Bethlehem, 26th; Easton, 26th; Aqueduct, 6th; Somerset, 6th; Lewisburg, 6th.

Hail.—Towanda, 6th, 10th; Emporium, 6th, 10th; Mauch Chunk, 6th, 10th; Phœnixville, 6th, 25th; Grampian, 5th; Lock Haven, 6th, 10th; Carlisle, 6th; Lebanon, 5th, 10th, 16th; Easton, 6th, 16th; Dyberry, 6th, 26th.

Snow.—Hamburg, 29th; Hollidaysburg, 2d, 6th, 10th, 13th, 16th, 26th, 28th, 29th; Towanda, 4th, 5th, 6th, 10th, 13th, 14th, 16th, 17th, 18th, 22d, 25th, 29th, 30th; Quakertown, 3d, 4th, 6th, 8th, 9th, 10th, 13th, 16th, 19th,

22d, 23d, 26th, 28th, 29th, 30th; Cassandria, 2d, 8th, 10th, 13th, 16th, 19th, 22d, 23d, 27th, 29th; Johnstown, 2d, 4th, 8th, 10th, 11th, 12th, 13th, 14th, 15th, 16th, 18th, 19th, 22d, 23d, 24th, 25th, 26th, 27th, 28th, 29th, 30th; Emporium, 1st, 3d, 4th, 5th, 6th, 10th, 13th, 14th, 15th, 16th, 17th, 18th, 19th, 21st, 22d, 23d, 24th, 25th, 26th, 28th, 29th, 30th; Mauch Chunk, 3d, 9th, 10th, 13th, 16th, 19th, 26th, 29th; State College, 2d, 3d, 6th, 8th, 10th, 11th, 13th, 14th, 16th, 17th, 18th, 22d, 23d, 25th, 26th, 28th, 30th; West Chester, 9th, 13th, 29th, 30th; Coatesville, 3d, 4th, 8th, 9th, 13th, 16th, 22d, 26th, 29th, 30th; Kennett Square, 3d, 8th, 9th, 10th, 13th, 28th, 29th; Phœnixville, 2d, 3d, 9th, 28th, 29th; Grampian, 2d, 4th, 5th, 10th, 13th, 16th, 22d, 26th, 29th, 30th; Lock Haven, 6th, 10th, 13th, 14th, 16th, 19th, 21st, 25th, 26th, 29th; Saegerstown, 1st, 3d, 4th, 9th, 12th, 13th, 14th, 15th, 19th, 23d, 24th, 26th, 29th; Carlisle, 3d, 8th, 13th, 26th, 29th; Harrisburg, 3d, 8th, 10th, 13th, 19th, 26th, 28th, 29th; Uniontown, 2d, 4th, 8th, 12th, 13th, 25th, 28th; Chambersburg, 2d, 8th, 13th, 25th, 28th, 29th; Huntingdon, 2d, 8th, 10th, 13th, 16th, 19th, 22d, 25th, 29th; Lancaster, 2d, 8th, 14th, 17th, 26th, 29th; Lebanon, 2d, 3d, 8th, 9th, 10th, 13th, 16th, 19th, 22d, 23d, 26th, 28th, 29th, 30th; Coopersburg, 3d, 4th, 8th, 9th, 13th, 16th, 29th; Drifton, 2d, 4th, 10th, 16th, 18th, 27th, 28th; Wilkes-Barre, 8th, 16th, 26th, 29th; Greenville, 3d, 4th, 6th, 13th, 14th, 24th, 28th; Pottstown, 3d, 25th, 29th; South Bethlehem, 8th, 16th, 26th, 28th, 29th; Easton, 8th, 13th, 16th, 19th, 26th, 29th, 30th; Aqueduct, 2d, 8th, 10th, 13th, 16th, 19th, 22d, 23d, 25th, 26th, 29th, 30th; *Philadelphia* [Centennial Avenue], 3d, 9th, 28th, 29th; Blooming Grove, 8th, 10th, 13th, 16th, 18th, 29th; Shingle House, 2d, 4th, 14th, 18th, 22d, 26th; Somerset, 7th, 9th, 12th, 15th, 18th, 23d, 25th, 26th, 28th, 29th; Wellsboro, 5th, 10th, 13th, 16th, 19th, 26th, 28th; Lewisburg, 13th, 16th, 19th, 26th, 28th, 29th; Dyberry, 3d, 4th, 5th, 6th, 8th, 10th, 13th, 14th, 16th, 19th, 26th; Honesdale, 4th, 5th, 6th, 10th, 13th, 16th, 19th, 26th, 29th; Salem Corners, 4th, 6th, 8th, 9th, 10th, 13th, 16th, 17th, 19th, 22d, 23d, 26th, 29th; Lycippus, 3d, 13th, 17th, 23d, 29th; South Eaton, 6th, 10th, 13th, 16th, 17th, 23d, 26th, 29th; York, 2d, 3d, 8th, 9th, 10th, 12th, 13th, 16th, 19th, 25th, 28th, 29th.

Sleet.—Hollidaysburg, 6th, 10th, 20th; Towanda, 6th, 10th, 25th; Cassandria, 6th, 25th; Johnstown, 5th; Emporium, 6th; Mauch Chunk, 6th, 10th, State College, 6th; Grampian, 6th; Lock Haven, 6th, 10th; Saegerstown, 25th; Lebanon, 5th; Coopersburg, 6th, 16th; Wilkes-Barre, 25th, 26th; Greenville, 5th; Aqueduct, 5th, 25th; *Philadelphia* [Centennial Avenue], 8th, 25th; Somerset, 5th, 25th; Dyberry, 6th, 10th; Honesdale, 26th; York, 6th, 10th, 25th.

Aurora.—Hollidaysburg, 11th; Le Roy, 19th; Saegerstown, 2d.

Solar Halo.—Le Roy, 9th, 28th; *Philadelphia* [Centennial Avenue], 5th, 7th, 25th.

Lunar Halo.—Le Roy, 9th; Towanda, 2d, 9th; *Philadelphia* [Weather Bureau], 5th, 15th; [Centennial Avenue], 5th.

Meteors.—Philadelphia [Centennial Avenue], 29th.

Parhelias.—Le Roy, 14th, 24th; Towanda, 24th.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin																																
Bethlehem,			.85				.34		.98							.51					.05					1.12			.19			4.04
Blooming Grove,								.76		.20	.86		.10			.55		.22								.93			.30			3.92
Brewers Lock,			.02				.74	.24	.13	.21	.55		.23			.64					.08					1.78			.30			4.82
Coatesville,			.01	.01		.77	.02	.27	.05	1.04	.09		.05			.91					.08	.03				1.30		.20	.25			5.08
Cooperburg,			.02	.02		.85	.02	.27	.05	.51	.41		.14			.43					.05	.03				1.18			.21			4.19
Doylestown,						.73		.27	.07	.46	.27					.24					.09					1.32			.23			3.78
Dyberry,					.10	.61	.22	.21		.21	.10		.10			.34		.18	.30		.05					.85			.28			2.85
Easton,								.34			.38		.02			.31			.01		.08					1.08			.20			3.16
Forks of Neshaminy,			.06			.67		.38		.80	.03		.19	.04		.02					.09					2.00			.17			4.98
Frederick,			.02			.78		.25		.40	.33		.19			.46					.06	.03				1.44			.29			4.19
Hamburg,		.40				1.40	.11	.30		.89			.18			.46					.19					1.40			.29			5.82
Honesdale,				.02	.10	.62	.21	.09		.28	.32		.14			.38			.07		.34	.01				.80			.05			3.68
Kennett Square,			.04			.66	.04	.10	.16	.88	.18		.20			.74					.13					1.89		.20	.40			5.30
Lansdale,			.01			.75		.33	.05	.75	.31		.20			.60					.05					1.61			.41			5.09
Mauch Chunk,			.04			.95	.16	.25	.05	.35	.30		.33			.47			.10		.04	.02				1.25			.15			5.06
Ottsville,						.75	.05	.33		.44	.50					.39										1.29			.18			3.93
Philadelphia, a†			.01			.55	.01	.08	.10	.93	.25		.28			.69					.09					1.20		.07	.38			4.52
Philadelphia, b,			.01			.54	.08	.13	.11	.33	.24		.19			.80					.08					1.65		.07	.30			5.06
Phoenixville,		.06				.56	.01	.26	.10	.62	.25		.20			.75			.03		.12	.07	.01			1.69		.08	.30			5.47
Point Pleasant,						.64		.20	.12	.70	.36		.20			.53					.13					1.44			.26			4.63
Pottstown,			.05			1.90		.15		1.40						.60					.15				.10	1.80			.30			5.65
Quakertown,						.47	.05	.28	.23		.55		.07			.56			.03			.13				1.30			.22			3.73
Reading,			.01			.63	.06	.36	.06	.55	.22		.17			.45			.01		.01	.20				.32		.01	.28			3.56
(Salem Corners) Hamilnton,				.05		.33	.22	.14	.04	.37	.71		.30			.52	.10		.27			.05	.02			.37			.25			4.42
Selsholtzville,						.52		.38	.04	.76	.31					.56					.12					1.07			.25			4.40
Smith's Corner,						.77		.30	.07	.64	.32		.09			.55					.06					1.38			.25			4.47
Swarthmore,																																
West Chester,			.02			.60	.02	.20	.05	.67	.18		.31			.59					.09					1.74		.29	.27			4.95
Westtowa,																																
Susquehanna Basin.																																
Altoona,						.79	.28	.04		.60	.07	.20	*	.17		.27			.02		.15	.17				.38		.38				
(Aqueduct) Logania,		.03				.55	.10	.45		.57	.18		.17			.43			.06		.11	.03				.47		.03	.24			3.72
Carlisle,			.08			.58	.05	.30	1.10	.18	.05		.28			.58										.28			.25			3.79
Drifton,	*	.10		.05		4	.54	.12		.20	.35		*			.20		.15									.05	.05				3.74
Emporium,				.03		.78	.02	.22		.35	.30					.20		.03	.30		.15	.04			.26	.21		.03		.20		1.69
Girardville,				.13		.44	.28	.21		.90			.26			.45					.14	.09	.04		.26	.26		.28				4.78
Grampian,		.03		.20	.44	1.18	.70			.72	.24		.28			.68			.22		.24	.15				.48			.28	.05		3.84
Harrisburg, †			.20			.34	.04	.29	.03	.68	.19		.02			.44			.01		.12	.03				.79		.08	.24			5.10
Hollidaysburg,		.04				.88	.28	.20		.50	.22		.17			.41			.34		.20	.09				1.27		.12	.25			3.80
Huntingdon,		1.35						.23		1.01			1.18			.23			.26		.35	.05			.45			.25			5.74
Kilmer, ‡																																5.16
Lancaster,		.05				2.00		.10		‡	‡	.81		.21			.30					‡	.21			.05		‡	.25			4.77
Lebanon,		.01	.03			1.10	.04	.53	.05	.38	.18		.27			.46			.22		.08	.06				1.18		.05	.20			4.76
Le Roy,				.03		.40	.03			.72	.20		.40			.20			.40		.08	.01				.40			.20	.03		3.27
Lewisburg,						.18	.16	.05		.72	.05		.05			.30			.05		.40					.32		.20	.28			3.15
Lock Haven,						.80	1.05			.60	.77		.40	.10		.40			.30		.01				.20	.30			.20			4.73
Salina Grove,																																
South Eaton,						.29	.14	.08		.53	.18		.15			.43			.50			.05				.80			.06			2.35
State College,						.52	.39			.73	.15		.40			.40					.15	.06	.03		.10	.44		.08	.20			4.18
Towanda,						.20	.20	.08		.60			.10			.20		.20							.28				.15			1.93
Wellsboro,					.60	.05				.70	.05		.30			.25			.30							.30		.25	.18			3.00
Wilkes-Barre,							1.53	.40		1.38						.72						.02				.28			.18			3.43
York,			.06			.74	.20	.40	.20	.48	.18		.25			.48			.02		.08					.72		.15	.13			4.03

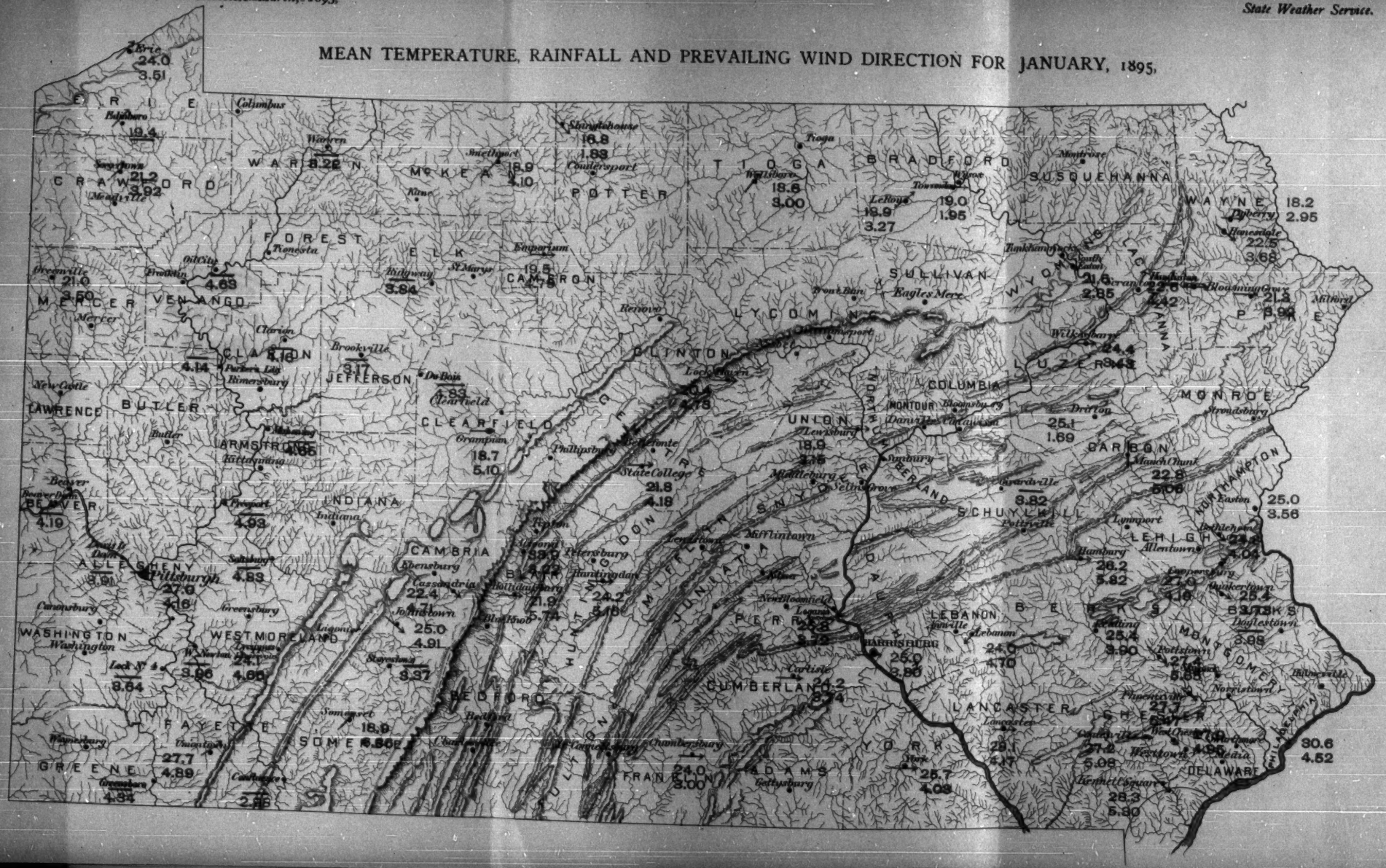
†U. S. Weather Bureau Stations. *Missing. ‡Amount included in measurement following. ‖Discontinued.

DURING JANUARY, 1895.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,			.03	.01		.87	.62	.14		.72	.76		.07	.01		.90			.96		.01	.96				.56			.07			4.19
Brookville,				.10		.17	.61	.05		.14	.45		.32	.25	.02	.22	.04		.18		.08	.22	.05			.84	.04		.12	.03		3.77
Cassandria,						.84	.36			.35	.16		.45			.30			.30		.20	.40	.20			.63			.30			4.71
Clarion,			.05	.04		.63	.99	.21		.38	.32		.31	.07	.03	.13	.04		.35	.01	.07	.12	.03	.01		.74	.04		.12	.06	.02	4.16
Confluence,		.01	.09	.01	.57	.10	.23	.04	.03	.36		.04	.03		.25			.11	.09	.05	.30	.01	.02		.40	.02		.20				2.98
Davis Island Dam,			.03			.48	.59	.20		.58	.67		.20	.10		.40	.07		.05		.06	.03	.05			.40			.10			3.31
DuBois,			.05	.07		1.18	.72	.18		.38		.32	.25			.17		.03				.26	.14			.93	.05		.09	.03	.08	4.83
Elwood Junction,						.80	.65	.12		.33	.31	.21		.03		.08			.19		.30	.09				.40			.20			4.25
Freeport,			.20	.06		.74	.90	.20		.71	.20		.29	.22		.35	.20		.20		.08	.10	.08			.54	.08		.26	.04		4.93
Greensboro,			.05	.03		.40	.90	.20	.14	.70	.35		.18	.08		.45	.05		.03		.05	.13	.02	.01		.43			.16	.02		4.34
Greenville,			.30	.40		.30	.16	.40		.80	.11		.21	.23							.34			.10					.05			3.30
(Immel Reservoir)																																
Lycippus,			.15			.73	.60	.15	.07	1	1.39		.26				.53		.07			.13	.07			.34			.15			4.66
Johnstown,		.08		.02		1.67	.28	.07		.10	.09	.05	.18			.45		.03	.30		.09	.11	.02		.08	.32		.09	.03	.01		4.91
Lock No. 4,			.11	.04		.47	.48	.12		.60	.30		.12	.03		.45			.03		.03	.10	.01			.20			.15			3.64
Mahoning,				.24		1.40	.76	.08		.41	.55		.23	.05		.13					.14	.20	.06			.09	.01		.08	.02		4.63
Oil City,				.07		.94	.50	.27		.32	.61		.32	.30	.02	.05			.30		.02	.21		.02		.55	.06		.06	.01		4.63
Parker's Landing,				.06	.01	.60	.65	.21		.32	.80	.11	.18	.10	.04	.13		.01	.32		.08	.09	.03		.01	.30	.04		.11	.04		4.14
Pittsburg,†		.03	.01	.03	.01	.86	.40	.02		1.03	.16	.02	.18	.02		.52			.04		.08	.07			.19	.40		.05	.03	.01		4.26
Ridgway,				.09		.82	.55	.20		.29	.38		.21	.11		.25			.31			.19				.48			.05	.01		3.84
Saegertown,				.22	.95	.40			.30	.28			.50	.28							.25		.10			.44						3.99
Saltsburg,	.03		.07	.05		.64	.66	.40		.57	.49	.03	.19	.23							.04	.20	.06	.02		.34	.13		.12	.04		4.83
Shingle House,		.20		.06						.25				.30				.38	.14	.01		.10				.60						4.83
Smethport,				.15		.50	.50	.25		.80	.20		.20						.40			.30				.80						4.10
Somerset,					.1.30	.55	.21		.60			.31				.42			.24	.30		.25			.60	.54		.22	.10			6.96
Stoyestown,				.20		.15	.21	.36	.22	.71	.17	.10		.25							.20	.20	.10	.20		.20			.20			3.37
Uniontown,		.09		.01		1.16	.24	.33	.04	.84	.06	.25	.09		.22	.63			.06						.26	.03			.65			4.89
Warren,				.10		.79	.31	.14		.31	.16		.29	.31	.09			.01	.11	.01		.45	.01			.19	.09		.08	.10			3.22
West Newton,			.12	.03		.37	.65	.20	.02	.50	.74	.02	.19	.05		.41	.13		.04		.06	.13	.04			.22			.14			3.96
Potomac Basin.																																
Chambersburg,		.02				.45	.06	.57		.20	.15		.20			.48					.01				.05	.60		.17	.14			3.00
Lake Basin.																																
Erie,†				.20		.14	.10			1.04	.05	.09	.32	.49	.04			.04	.27		.12	.20		.02		.40	.03	.05		.02		3.51

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for January, 1895.

County.	Station.	Elevation above Sea Level (feet).	Temperature. Mean.	Maximum. Highest.	Maximum. Date.	Minimum. Lowest.	Minimum. Date.	Mean of Maximum.	Mean of Minimum.	Daily Range. Mean.	Daily Range. Greatest.	Precipitation. Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow.	Number of Days. Clear.	Fair.	Cloudy.	Wind. Prevailing Direction.	Observers.
Allegheny,	Pittsburgh,	820	27·0	58	21	—5	13	34·3	19·4	14·9	42	4·16	8·3	. . .	21	7	9	15	W	O. D. Stewart, W. B.
Berks,	Hamburg,	380	26·2	47	6	2	13	32·8	19·7	13·1	30	5·88	3·0	. . .	10	5	17	9	W	William Shipe.
Berks,	Reading,[3]	280	25·4	. . .	. .	. .	. .	. .	. .	. .	. .	3·90	. . .	. . .	15	. .	. .	. .	. .	Franklin Yager.
Blair,	Altoona (30 days),	1,181	33·9	68	24	9	5	42·5	25·3	17·2	47	3·22	. . .	. . .	13	. .	. .	. .	. .	Dr. C. B. Dudley.
Blair,	Hollidaysburg,	947	21·9	47	7	—11	5, 31	33·0	10·8	22·2	44	3·74	21·0	10·0	14	11	5	15	W	Prof. J. A. Stewart.
Bradford,	Le Roy,	1,400	18·9	46	7	—4	23, 28	26·6	11·2	15·4	26	3·27	21·7	16·0	14	4	7	20	SW	G. W. T. Warburton.
Bradford,	Towanda,	754	19·0	44	7	—16	1	28·1	10·0	18·1	33	1·95	20·5	8·0	9	5	10	16	W	Hiram E. Bull.
Bucks,	Forks of Neshaminy,	304	31·4	. . .	. .	. .	. .	. .	. .	. .	. .	4·98	5·0	. . .	11	20	1	10	W	J. C. Hilsman.
Bucks,	Quakertown,	536	25·4	50	7	2	5	33·5	17·2	16·3	31	3·73	8·0	3·0	11	4	18	9	NW	J. L. Heacock.
Cambria,	Cassandria,	2,100	22·4	51	7	—14	31	28·9	15·9	13·0	40	4·71	27·0	15·0	12	. .	. .	19	NW	A. H. Boyle.
Cambria,	Johnstown,	1,184	25·0	48	21	—5	13	33·0	16·9	16·1	36	4·91	15·0	8·0	20	3	5	23	NW	E. C. Lorentz.
Cameron,	Emporium,	1,050	19·5	43	11	—17	31	29·3	9·7	19·6	37	4·79	25·9	15·0	16	3	13	15	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	22·8	43	7	1	5, 13	32·0	13·6	18·4	32	5·06	13·5	8·0	14	11	7	13	N	F. C. Wintermute.
Centre,	State College— Agricultural Experiment Sta.,	1,191	21·8	46	7	—5	5, 23	30·7	13·0	17·7	33	4·18	23·8	17·0	14	6	9	16	W	Prof. Wm. Frear.
Chester,	West Chester,	455	27·9	49	11	7	13	35·2	20·6	14·6	33	4·95	6·8	2·0	13	12	4	15	NW	J. C. Green, D.D.S.
Chester,	Coatesville,	380	27·2	48	7	5	5	35·9	18·6	17·3	31	5·08	7·2	4·0	15	8	15	8	W	W. T. Gordon.
Chester	Kennett Square,	275	28·3	51	7	7	5	37·4	23·2	18·2	31	5·30	8·5	5·0	13	9	9	13	NW	B. P. Kirk.
Chester,	Phœnixville,	190	27·7	50	7	5	13, 14	35·2	20·2	15·0	32	5·47	12·0	8·0	16	7	4	20	NW	Knowles Croskey.
Chester,	Westtown †,	350	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	John D. Carter.
Clearfield,	Grampian,	1,450	18·7	50	7	—12	31	25·5	11·9	13·6	32	5·10	28·0	24·0	15	1	17	13	W	Nathan Moore.
Clinton,	Lock Haven,[1]	560	20·4	49	11	—13	31	. .	. .	. .	. .	4·73	29·1	10·0	Rs	3	2	26	W	Prof. J. A. Robb.
Crawford,	Saegertown,	1,200	21·2	50	21	—12	31	32·3	10·1	22·2	51	3·92	18·0	8·0	10	3	11	17	SW	J. G. Apple.
Cumberland,	Carlisle,	480	24·2	45	11	2	5	32·3	16·1	16·2	31	3·74	10·5	8·0	11	11	8	12	W	J. E. Pague.
Dauphin,	Harrisburg,	480	25·0	44	7	2	13	31·0	20·0	11·0	25	3·80	9·5	7·0	15	6	12	13	W	F. Ridgway, W. B.
Delaware,	Swarthmore— Swarthmore College†,	361	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	Prof. S. J. Cunningham.
Erie,	Edinboro,[2]	190	19·4	45	21	4	17, 27	. .	. .	. .	. .	. .	. .	12·0	. .	. .	. .	. .	SW	C. F. Sweet.
Erie,	Erie,	1,400	24·0	55	21	—5	13	32·0	16·0	16·0	27	3·51	. . .	. .	18	2	10	19	SW	F. Wood, W. B.
Fayette,	Uniontown,	681	27·7	58	21	—7	13	35·2	20·2	15·0	33	4·89	14·0	. . .	17	5	16	10	SW	Wm. Hunt.
Franklin,	Chambersburg,	1,000	24·0	46	19	—3	1, 5	33·0	15·1	17·9	35	3·00	7·0	. . .	13	10	3	18	W	J. C. Boggs.
Huntingdon,	Huntingdon— The Normal College,	650	24·2	45	19	—7	5	33·9	14·5	19·4	41	5·16	15·5	10·0	10	1	21	9	W	Prof. W. J. Swigart.
Lancaster,	Lancaster— Franklin and Marshall Col'ge,	413	28·1	57	7	1	1	39·1	17·1	22·0	44	4·17	7·8	3·5	9	11	11	9	W	A. V. Heister.
Lebanon,	Lebanon,	458	24·0	44	7	0	31	32·8	15·2	17·6	34	4·70	15·1	4·5	16	6	13	12	NE	G. W. Hayes, C. E.
Lehigh,	Coopersburg,	550	27·0	46	7	5	5	35·4	18·7	16·7	29	4·79	7·3	3·0	14	12	6	13	SW	Dr. M. H. Boyé.
Luzerne,	Drifton (26 days),	1,688	25·1	49	7, 11	—3	23	39·2	11·0	28·2	48	1·69	8·0	11·0	9	6	4	16	. .	J. R. Wagner.
Luzerne,	Wilkes-Barre,	575	24·4	47	7	—2	1	33·5	15·4	18·1	36	3·43	13·0	8·0	7	16	4	11	W	A. W. Betterly.
McKean,	Smethport,	1,500	18·9	47	7	—16	31	27·7	10·1	17·6	44	4·10	20·5	. . .	10	6	11	14	SW	Armstrong & Brownell.
Mercer,	Greenville— Thiel College,	1,000	21·0	51	21	—10	5	31·1	10·8	20·3	49	3·50	15·5	6·0	12	5	6	20	. .	Prof. S. H. Miller.
Montgomery,	Pottstown,	150	27·4	49	7	6	5	33·7	21·0	12·7	24	5·65	4·3	2·0	9	9	10	12	NW	Charles Moore, D.D.S.
Northampton,	Bethlehem,	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	4·04	. . .	. .	. .	. .	. .	. .	. .	J. E. Luckenbach.
Northampton,	South Bethlehem,	339	24·8	48	7	5	5	31·5	18·1	13·4	24	. .	6·0	4·0	. .	6	10	15	NW	T. Merriman.
Northampton,	Easton— Lafayette College,	325	25·0	49	7	0	5	33·1	16·9	16·2	32	3·56	7·2	. . .	8	9	10	12	. .	J. W. Moore.
Perry,	(Aqueduct) Logania,	367	25·8	50	7	—1	1	34·6	17·1	17·5	30	3·72	11·8	6·0	14	11	10	10	NW	Richard Callin.
Philadelphia,	U. S. Weather Bureau,	117	30·6	55	7	10	13, 14	37·2	24·0	13·2	26	4·52	4·6	2·8	13	8	11	12	NW	L. M. Dey, W. B.
Philadelphia,	1529 Centennial Avenue,	120	30·8	53	7	11	5	37·4	24·2	13·2	26	5·06	4·8	3·0	13	7	13	11	NW	John Comly.
Pike,	Blooming Grove,[2]	21·3	40	7	—6	5	. .	. .	. .	. .	. .	3·92	15·0	20·0	8	9	12	10	W	John Grathwohl.
Potter,	Shingle House,	1,475	16·8	44	21, 22	—15	31	26·9	6·8	20·1	38	1·83	25·8	18·0	7	8	8	15	NW	H. L. Pearsall.
Snyder,	Selins Grove†,	455	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	J. M. Boyer.
Somerset,	Somerset,	2,250	18·9	48	21	—13	12	27·8	10·0	17·8	36	6·36	32·0	10·0	14	1	10	20	SW	W. M. Schrock.
Tioga,	Wellsboro,[2]	1,327	18·6	45	7	—16	31	. .	. .	. .	. .	3·00	25·0	30·0	9	3	9	19	SW	H. D. Deming.
Union,	Lewisburg	450	18·9	44	11	—15	1	31·1	6·7	24·4	38	3·13	14·0	10·0	12	2	5	24	W	Prof. W. G. Owen.
Wayne,	Dyberry,	1,100	18·2	47	7	—15	5	29·2	7·2	22·0	38	2·95	19·0	22·0	13	6	8	17	W	Theodore Day.
Wayne,	Honesdale,	1,000	22·5	49	7	—12	1	31·9	13·1	18·8	37	3·68	16·5	19·0	14	12	12	7	NW	Andrew Thompson.
Wayne,	(Salem Corners) Hamlinton,	1,600	22·6	50	7	—4	13	31·2	14·0	17·2	34	4·42	24·4	30·0	15	6	10	15	W	T. B. Orchard, M.D.
Westmoreland,	(Immel Reservoir) Lycippus,	1,420	24·2	55	7	—9	14	32·4	15·8	16·6	45	4·66	12·8	. . .	13	. .	. .	. .	. .	Murray Forbes.
Wyoming,	South Eaton,	660	21·6	47	7	—11	1	31·2	12·1	19·1	36	2·35	12·5	15·0	10	8	7	16	NW	B. M. Hall.
York,	York,	385	25·7	47	7	1	1	33·9	17·5	16·4	35	4·03	9·3	2·5	14	7	10	8	W	Mrs. L. H. Grenewald.

Mean temperature from maximum and minimum readings. * Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 + 4. [2] Mean temperature 8 + 8 + 2.
† No records. ‡ Records incomplete.

MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION FOR JANUARY, 1895.